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Application of Radar to Ballistic Acceptance Testing of Ammunition (ARBAT)

FINAL REPORT

February 1980

U.S. Army Armament Research and Development Command

ITT GILFILLAN

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Log 0509

APPLICATION OF RADAR TO BALLISTIC ACCEPTANCE TESTING OF AMMUNITION (ARBAT)

Final Report
CDRL: A005

5 October 1979

under
Contract No. DAAA-21-76-C-0546
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ABSTRACT

This report covers the results of the activity on the ARBAT program (Application of Radar to Ballistic Acceptance Testing of Ammunition) through 5 October 1979. Included in this report are: A technical description of the radar system, description of the system operation and operational procedures, and description and analysis of the Performance Demonstration Test results. Performance Demonstration Test results indicate that: the system concepts have been proven; The ARBAT radar system is capable of tracking artillery projectiles while providing real-time analysis, display of the trajectory characteristics, and permanent magnetic tape storage of the trajectory data for further off-line analysis.

The ARBAT Radar System is a range instrumentation radar optimized for the Research & Development and ballistic testing of ammunition projectiles. This radar provides test parameters of the projectile trajectory which are not currently measurable. The data output of the radar is available both on real-time displays, and as a permanent record for use in further off-line analysis.

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INTRODUCTION

Section 1

INTRODUCTION

The ARBAT (Application of Radar to Ballistic Acceptance Testing of Ammunition) program has been directed toward achieving substantial improvements in artillery ammunition testing. For example, ballistic testing, until recently, has been accomplished with instrumentation only at and near the gun site by pressure gages, velocity coils, high speed framing and/or streak cameras. Terminal ballistic data could only be gathered by visual and aural observation.

Recently, limited radar coverage of in-flight and terminal effects has been available, using modified surplus Army radar equipment or a few highly specialized radars intended only for a particular test item. The results from such testing, while both gratifying and continuing, has also pointed to the potentially great value of a radar system specifically designed to monitor ballistic tests of a wide variety of ammunition items.

The available radar systems, being of older design and using mechanically controlled dish antennas, have significant limitations such as:

a) Angular velocity and acceleration too slow to intercept and track high speed projectiles within the permissible radar siting geometries.

b) Since most of these radars are either pulse or CW Doppler type, the radars are limited to either a partial trajectory only, or radial velocity data capability.

c) The systems do not perform well, or in some cases cannot operate at all, in the high clutter and multipath environment typical to low trajectories and for all trajectories near launch and impact points.

d) Generally relatively low accuracy data is obtained.

The purpose of this report is to present a final summary of effort accomplished by ITT Gilfillan under contract DAAA-21-76-C-0546. This effort has been sponsored by the U.S. Army Munitions Production Base Modernization Agency, U.S. Army Development & Readiness Command (DARCOM) under the technical direction of Headquarters U.S. Army Armament Research & Development Command (ARRADCOM) Product Assurance Directorate. The final report includes the ARBAT system description, system operation, operator procedures, demonstration test results, physical characteristics, conclusions and appropriate recommendations.

1.1 OPERATIONAL OBJECTIVES

The ARBAT radar system is designed to provide instrumentation for ballistic acceptance and R&D test programs on government proving grounds. ARBAT has been designed to support all currently produced and anticipated future ammunition items including artillery projectiles, mortar rounds and rockets. The ARBAT system is of a special importance to the modern, more sophisticated ammunition items, requiring extensive instrumentation support, such as:

- Rocket assisted projectiles (RAPs)
- Improved Conventional Munitions (ICMs) cargo-carrying projectiles

isn't this part of ARRCOM?

During ballistic tests ARBAT is designed to measure all vital characteristics, such as: space position, true velocity, acceleration, drag, and radar cross section (rcs). Data outputs are available in real or near real time.

Because ARBAT provides processed output data in real time or immediately after the test firings, data concerning the performance of ammunition projectiles is immediately available to ammunition designers and manufacturers thus permitting rapid elimination of problems and/or improvement of performance.

The ARBAT program objectives are as follows:

- Early projectile acquisition
- Track complete trajectory
  (to 0.5 deg of radar horizon)
- Track wide variety of rounds
- Full Range
  - 15 km - Small Rounds
  - 30 km - Larger Rounds
- Accuracy
  - Range - 0.1% of Range
  - Velocity - 1 m/sec
  - az/el - 2 millirad
  - rcs - 2 dB
- Detect, monitor, record events
- Data
  - Display - Real time with hard copy
  - Recorded - Near real time analysis
- Multiple sequential firing site coverage

1.2 BACKGROUND

As a result of anticipated increasingly sophisticated future testing requirements, ARRADCOM initiated a program to develop an advanced radar system intended specifically for ballistic acceptance testing of ammunition. As a result of initial analysis, ARRADCOM, in conjunction with other Government agencies, determined that no existing radar (military or commercial), in unmodified form, could satisfy the future long term needs of ballistic testing at proving grounds.

there was no ARRADCOM in 1971

A study contract in 1971 was awarded to MITRE Corporation to investigate various alternatives and propose a system approach based on Government testing requirements. As a result of this study the MITRE Corporation proposed a base line design for a new radar system with the following features:

a) Coherent pulse radar system
b) Operating in C- or X-bands
c) High clutter cancellation capability

d) Antenna with:
   1) Electronic beam steering (with mechanical assist)
   2) Narrow pencil beam
   3) Low sidelobes
e) Digital signal and data processing
f) Real time data display

In 1972 a design study contract was awarded to ITT Gilfillan, based on a Government Specification resulting from the MITRE study. A final report and drawing package was developed during this design study effort. This final report also defined a multi-phase program which scheduled fabrication of the antenna; followed by fabrication, testing and documentation of the other major system elements. In 1973 ITT Gilfillan was awarded a contract to fabricate an X-band phase/frequency scan antenna for the ARBAT application.

there was no ARRADCOM in 1975

In 1975 there were currently in design ~~more radar systems~~ which were not available during the early phases of the program. Therefore, ARRADCOM decided in late 1975 to continue the program using a competitive approach. The objective was to assure the best possible combination of system performance at the least cost to the Government. This approach resulted in an award to ITT Gilfillan of an incrementally funded contract to complete the program in October 1976. This program was concluded with a series of demonstration tests in October 1979. Program delays were experienced for several reasons. Among these were delays due to funding limitations and delays due to equipment test and integration problems.

In general, it can be stated that the test results presented herein have verified the feasibility of the approach selected. Further, it can be stated, that although all objectives were not tested, further efforts recommended herein will definitely lead to a system which fully provides the necessary capabilities for future Government Proving Ground Test activities.

Section 2

ARBAT SYSTEM DESCRIPTION

Section 2

ARBAT SYSTEM DESCRIPTION

The ARBAT system was designed to fulfill the specialized mission of ballistic ammunition testing under proving ground conditions. The system organization and functional allocations applicable to the overall system in providing the operational performance required are discussed, followed by a description of the subsystems and their specific functions.

In general, the major group assemblies and their physical locations are housed in the major subsystems as shown in Figure 2-1. There are however, two major assemblies; the radar receive (2nd IF/ signal processor and power conversion unit, that perform their functions in both subsystems.

A discussion on both subsystems and the system software is contained in the following paragraphs.

2.1 ANTENNA SUBSYSTEM

The antenna subsystem major functional elements include the antenna with several subassemblies, the radar transceiver, and an ancillary group which includes the transport vehicle, dehydrator and low voltage power supplies for electronic assemblies associated with the antenna.

2.1.1 Antenna

The ARBAT system antenna is a horizontally polarized X-band planar array formed by 167 closely spaced parallel waveguide sections. Each section contains dual radiating slots produced by precision milling across the face of the array sections. Table 2-1 describes the system parameters of the ARBAT Antenna. The array aperture is 10 by 12 feet. Beam scanning is accomplished by a combination of electronic and mechanical means. The beam is scanned in elevation by four-bit diode phase shifters, whereas, azimuth scanning is by frequency variation and mechanical rotation of the array. The mechanical rotation capability is a maximum of ± 170 degrees which fulfills the requirements in ammunition testing applications. Provisions are included in the antenna back structure design for a mechanical adjustment (tilt) of 0 to 25 degrees in elevation. The back structure is designed to support the microwave waveguide assemblies, phase shifter power distribution network and logic beam steering buffer and the transceiver unit. In view of the less than 360 degree rotation required (±170°), a cable "windup" feature is used for the power and input/output lines to and from the antenna which eliminates the need for slip rings. A detailed sketch illustrating the back structure concept is shown in Figure 2-2. The individual 167 dual slot horizontal radiators are fed by a single vertical feed line via 90-degree waveguide twist and offset sections, followed by 4-bit, 16 state diode phase shifters. The arrays terminate at a vertical performance monitor line at the end opposite the feed line. The performance monitor line is a part of the performance monitor and fault location feature incorporated in the system design. Antenna performance determination is accomplished by the measurement of the combined residual RF energy collected at the extreme ends of the horizontal arrays (opposite the feed end). Coupling from the vertical feed line to the arrays

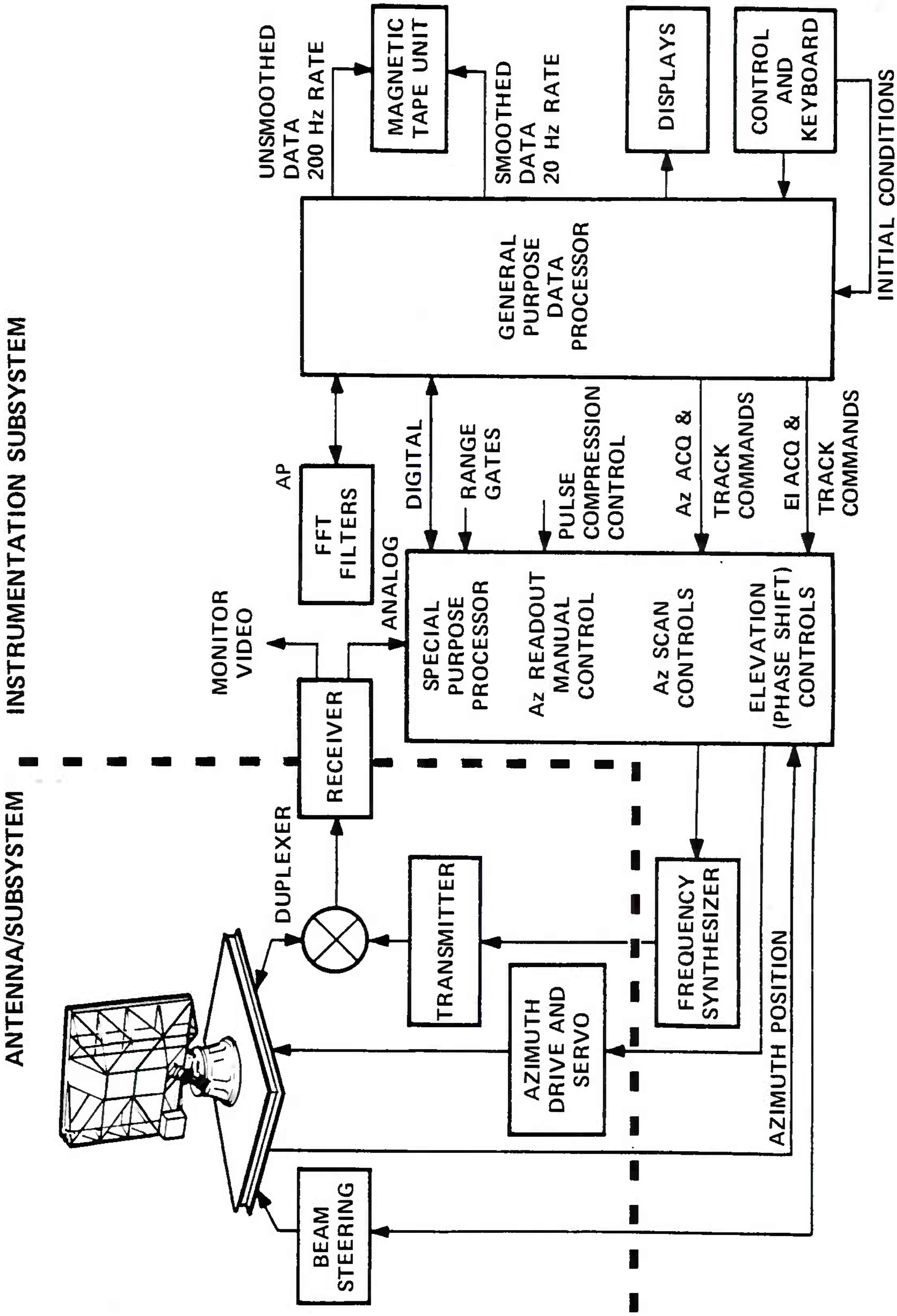

Figure 2-1. System block diagram

Table 2-I. Functional Performance

Beam Positioning

Azimuth: 7.7 degrees minimum

Rate of position variation: Limited only by logic state change time, signal propagation time and clock rate (22 MHz).

Scan Technique: Frequency variation (Synthesizer digital control)

Elevation: ±35 degrees minimum

Elevations scan technique: Phase control via diode phase shifters in each array waveguide section

Azimuth: ±170 degrees minimum

Azimuth rotation rate: 40 degrees/sec^2 minimum (servo control)

Elevation: +25 degrees by manual tilt-back (jack-screw mechanism)

Electrical Specifications

Frequency: X-band, 9.3 to 10 GHz

Scan (Azimuth) 7.7°

Scan (Elevation) ±35°

Beam size at center frequency:

Azimuth:	at 0° elevation:	0.55°
	at ±35° elevation	0.67°
Elevation:	at 0° elevation	0.66°
	at ±35° elevation	0.81°

Beam Pointing error (electrical)

Elevation	0.37 mrad.
Elevation beam switching time	1.0 MHz
Sidelobe level (at center frequency):	
Azimuth @ 0° elevation scan	-25 dB
@ ±35° elevation scan	-23 dB
Elevation @ 0° elevation scan	-25 dB
@ ±35° elevation scan	-23 dB
Terminal Gain @ 0° elevation scan at center frequency	46.0 dB min.

Note: The above specification is based on an average phase shifter insertion loss of 2.5 dB.

Power Capability:	30 kW peak 300W Avg.

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Table 2-I. Functional Performance (Continued)

Phase randomization technique (to avoid quantization error potential in 4-bit phase shifters: Insertion of dielectric blocks of varying size in each array path.

Signal Coupling	Taylor N4 (30 dB)
Mechanical Specifications	
Aperture Size	
Height	120.0 inches
Width	144.0 inches
Total Antenna Width	154.0 inches
Tilt Adjustment	25°
Pointing Accuracy	
(deflection error resultant from all loading)	
Azimuth	0.377 mrad max.
Elevation	0.184 mrad, max.
Antenna Assy Weight	1700 lbs max.

Note: The assembly includes the radar transceiver, beam steering buffer, and cables but excludes the pedestal.

Antenna Pedestal: Cast aluminum (Modified AN/SPS-48)

Turntable Bearing: Cross-axis roller bearing

Drive gear: Enclosed spur gear

Azimuth Rotation Limits: Servo interrupter switches and mechanical stop.

Data Takeoff Point: Direct from turntable

Takeoff gear type: Anti-backlash

Drive motor: Low inertia dc; rpm 1640 max.

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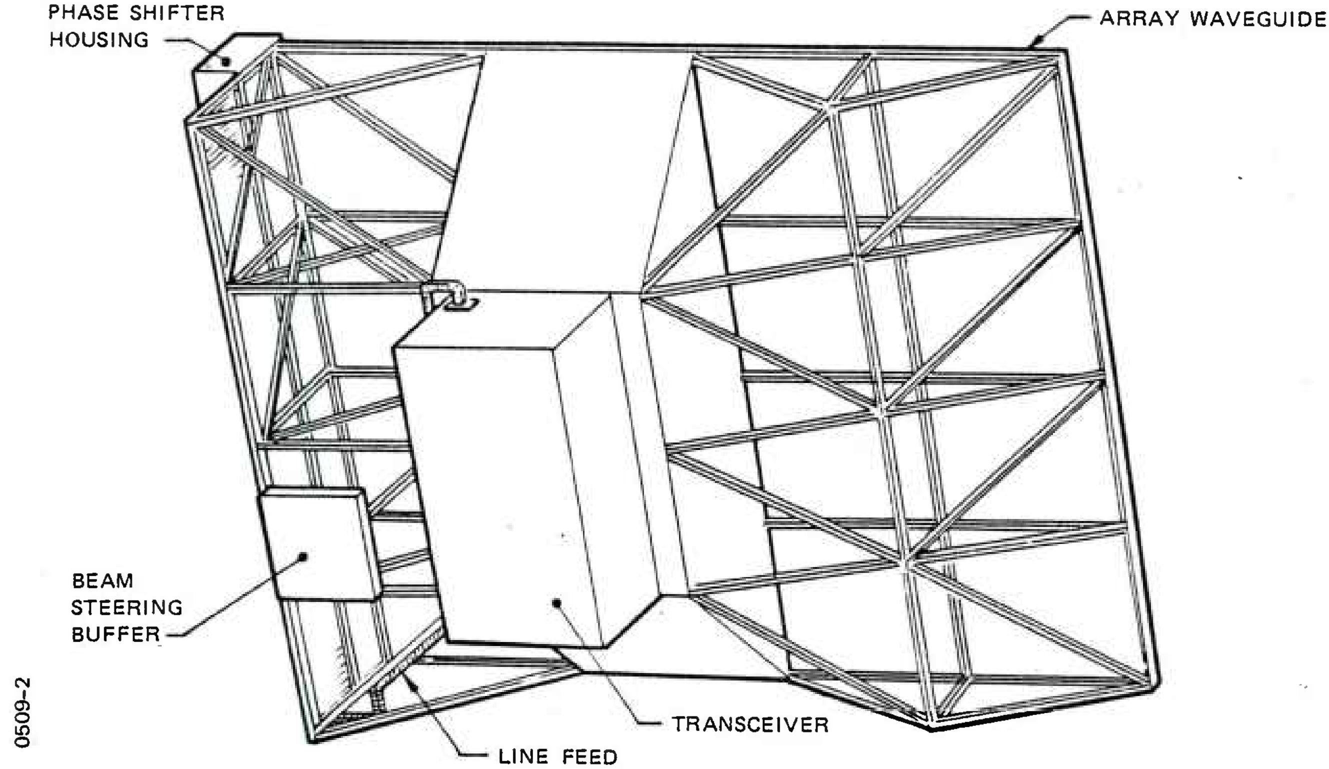

Figure 2-2. ARBAT antenna backstructure configuration.

and from the arrays to the performance monitor line is by 4-port coupler sections. Coupling sections at the feed end contain end loads and phase randomization blocks. The 4-port couplers at the performance monitor line section are designed with a common flange which mates with the individual flanges at the end of each horizontal array element. The performance monitor feature is implemented by connecting the lower end of the vertical performance monitor line section to a crystal video detector located in the Beam Steering Buffer housing by coaxial cable. The detector output is routed via coaxial cable to the monitoring circuitry located in the Special Purpose Processor (in van) after amplification. A pictorial drawing showing the microwave waveguide configuration and signal flow illustrates the basic antenna physical design, Figure 2-3. Figures 2-4 and 2-5 show the horizontal array elements back structure details, vertical feed line, 90 degree twist waveguide sections, and phase shifters.

ARBAT antenna test results are contained in the Antenna Test Report dated April, 1978, which was submitted as Data Item A007 under Contract DAAA-21-76-C-0546.

2.1.2 Beam Steering Buffer (BSB)

This major assembly contains circuitry which serves as the electronic interface between the beam elevation command generation logic in the Instrumentation Van and the phase shifters located on the antenna array proper. In addition to that function, the BSB housing and card cage contains other circuitry for interfacing the array temperature sensors and BITE (built-in test equipment) functions with the Instrumentation Van equipment (Antenna Performance and Interface card). The BSB

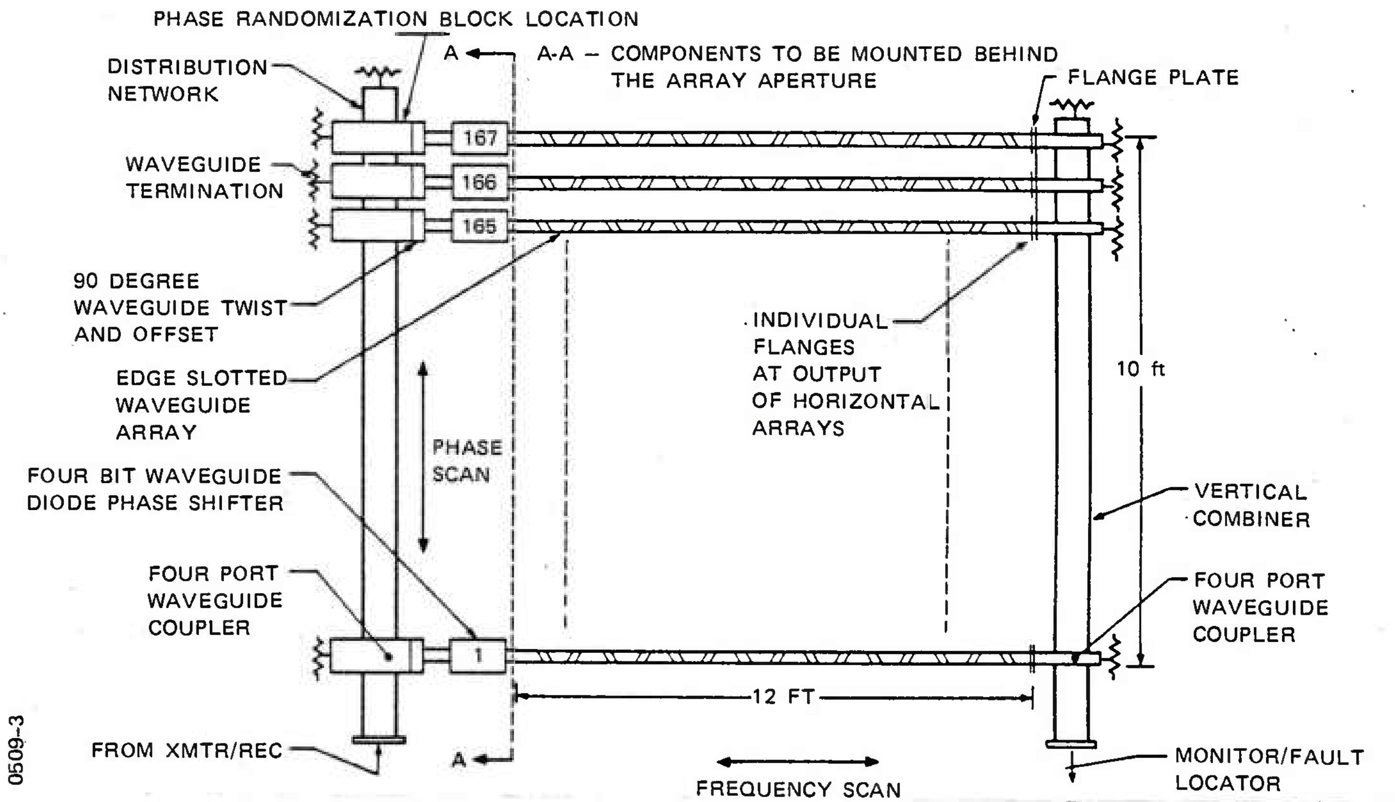

Figure 2-3. Antenna waveguide configuration and signal flow.

is mounted on the antenna support back structure. The mounting location is in close proximity to the phase shifters to avoid excessive propagation delay for command signals to the phase shifter drivers and for phase shifter bias loss sensory and transmitter shutdown BITE function signals.

2.1.3 Transceiver

2.1.3.1 Transmitter. The transceiver located on the Antenna Subsystem requires basic signal inputs which originate in the Instrumentation Van. These signals include timing and RF signals. For the purpose of the transmitter description, signals from the Instrumentation Van of concern are the COHO and Frequency Synthesizer signals. Figure 2-6 shows the general division of transceiver related functional blocks between the antenna subsystem and the instrumentation van. The transceiver receives synthesizer output signals varying in frequency from 232.8 to 252.8 MHz. These frequencies (512 steps) are selected digitally in normal operation by the General Purpose Computer in the van. Local oscillator frequencies in the above range are sent to the transceiver over triaxial cable and are processed by multiplication in a 36x multiplier after which the signal is further processed by up and down conversion. In the transmitter function the multiplied and further processed original LO signal from the van is used as the input drive to the first stage TWT, which in turn outputs the RF drive for the final output TWT stage. A simplified block diagram of the transmitter exciter function is shown in Figure 2-7. An abbreviated block diagram of the transmitter final output stage is shown in Figure 2-8.

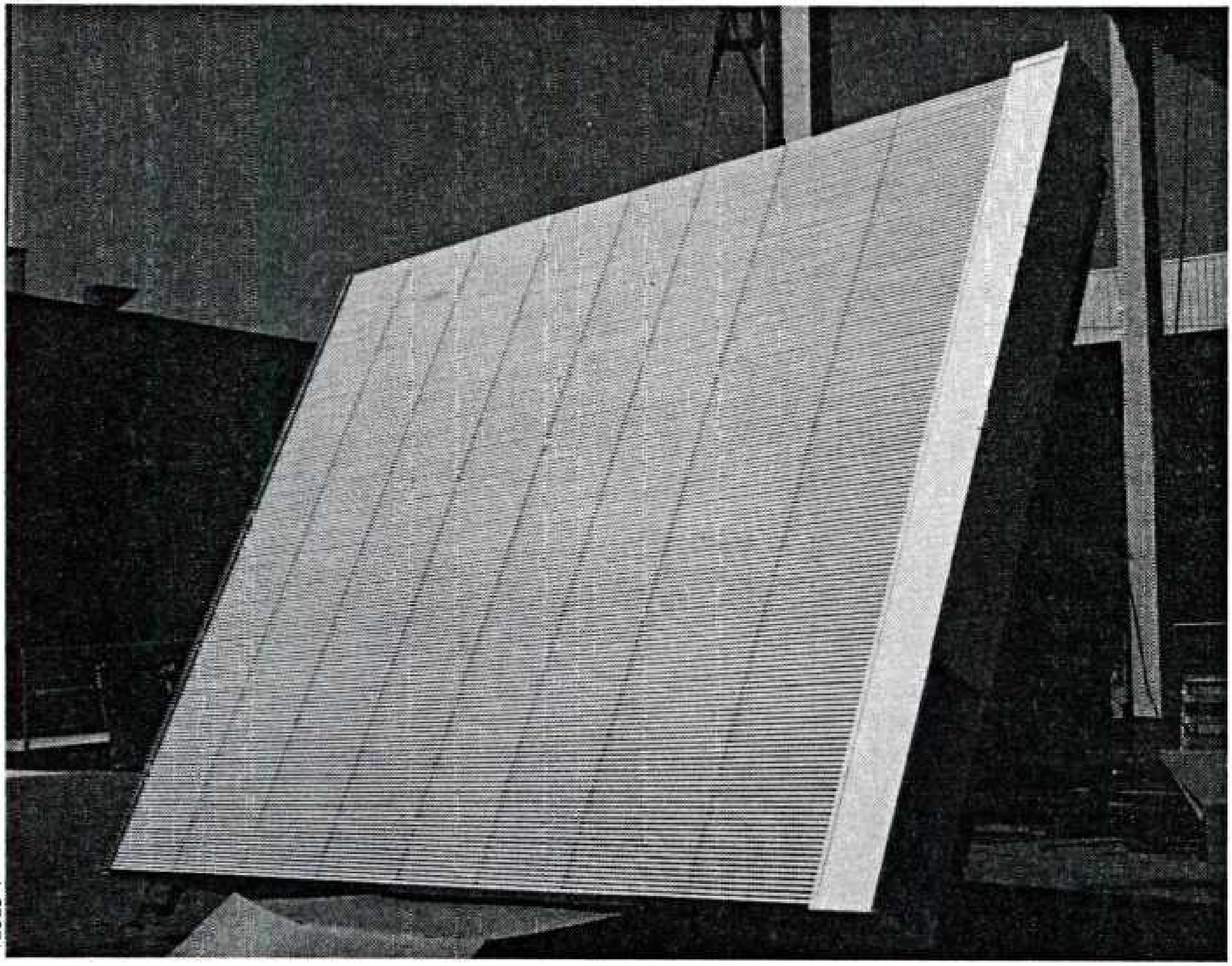
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Figure 2-4. ARBAT antenna assembly, front view

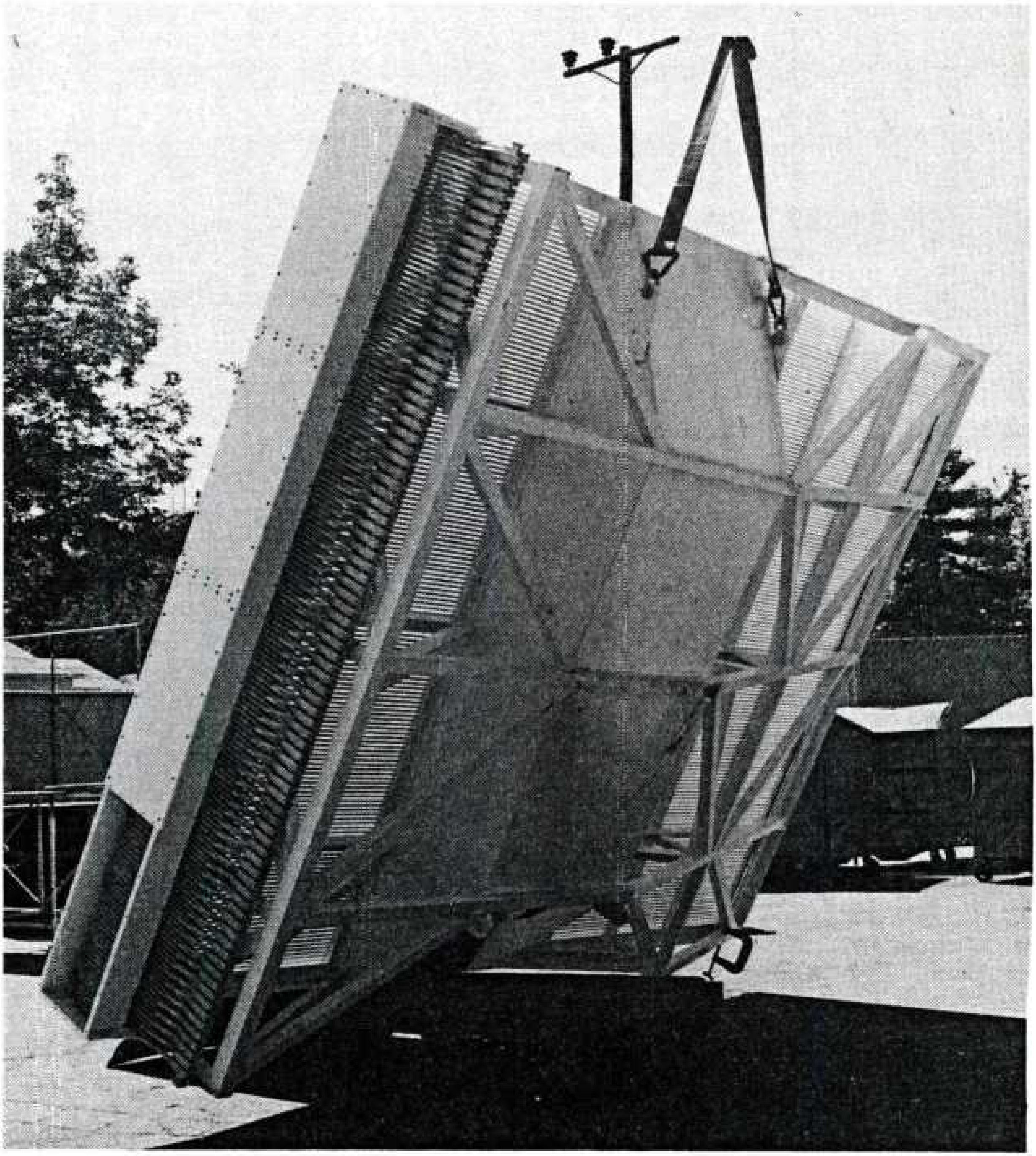

Figure 2-5. Antenna assembly, rear view

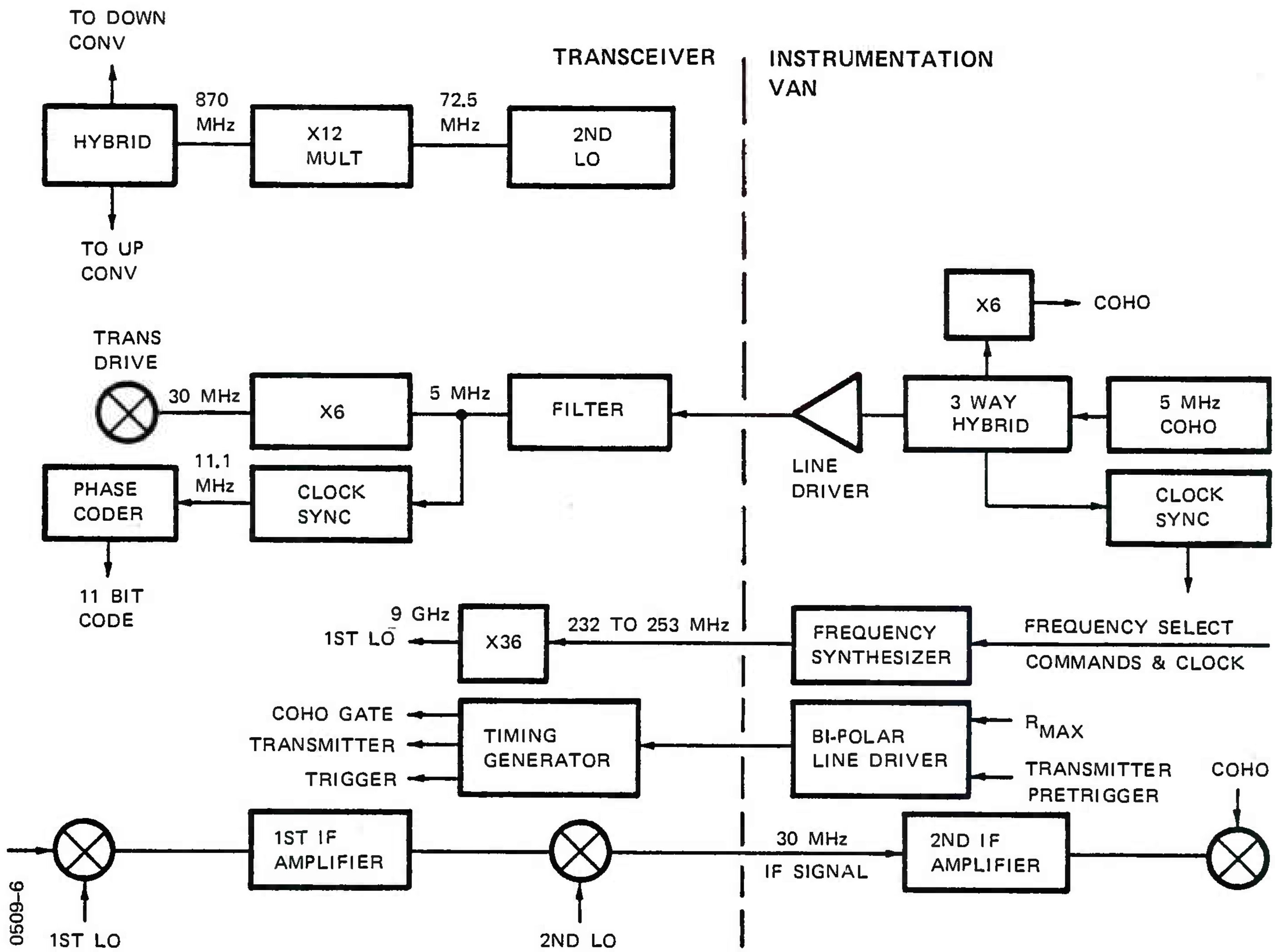

Figure 2-6. Division of functions between transceiver and van

Transmitter-Exciter Functional Section

The purpose of the transmitter-exciter functional section is to up-convert the sum of 30 MHz-COHO and second local oscillator frequencies to the X-band frequencies required to drive the first-stage TWT in the transmitter. The following paragraphs describe the functional operation of the transmitter-exciter circuits of the transceiver.

Transmitter Drive Signal Flow

Signal flow for the transmitter-exciter function begins at the double-balanced mixer CR30 of the same type as the second mixer in the receiver front end. The resultant 900 MHz signal passes through the 900 MHz bandpass filter FL20, the 900 MHz medium power RF amplifier AR4, and the X-band modulator A6 to reach the transmitter. Because the chain consists of IF and RF

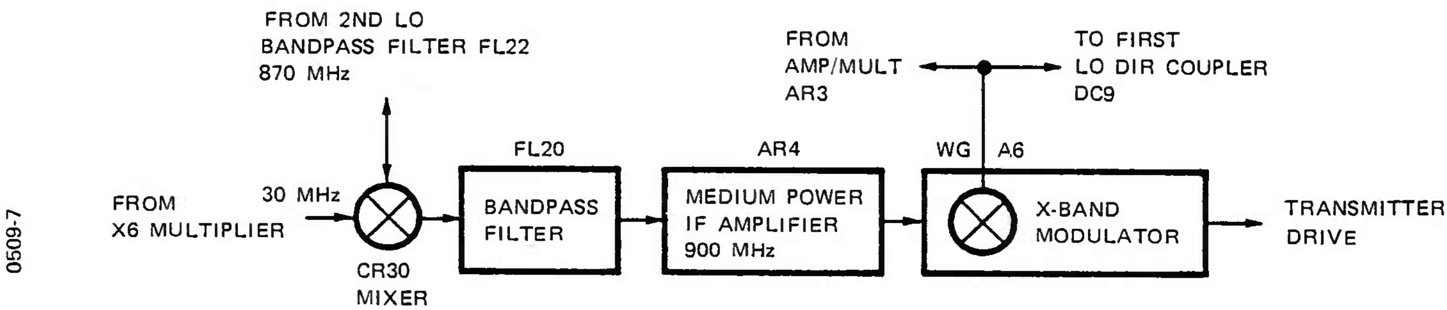

Figure 2-7. Transmitter-Exciter block diagram

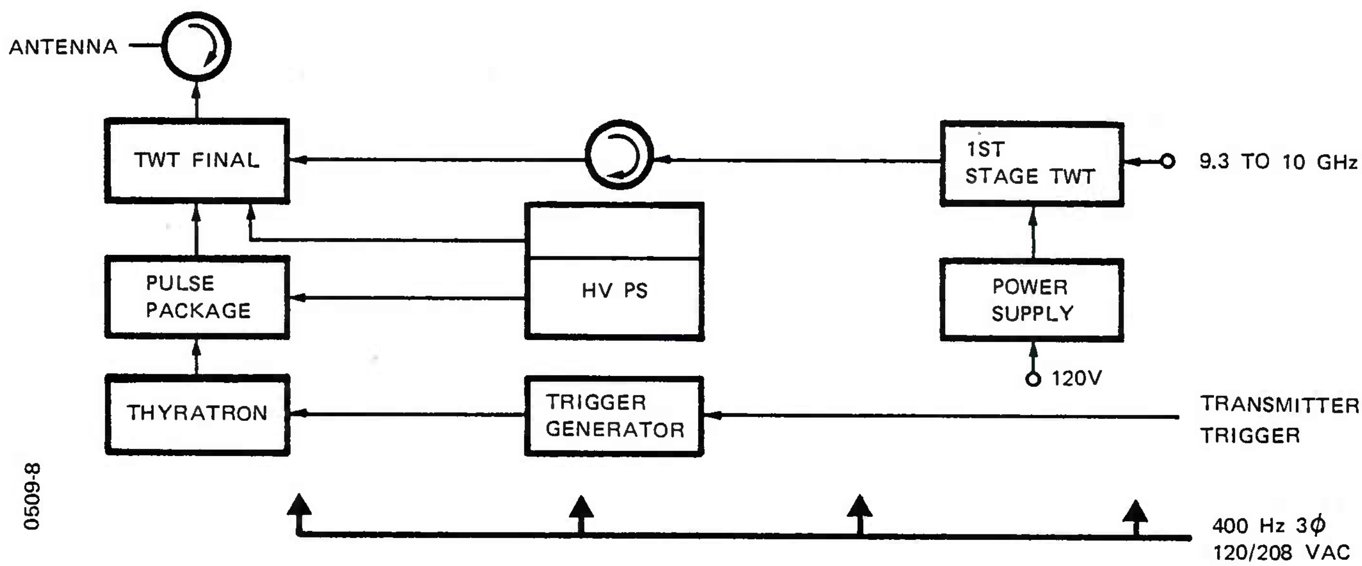

Figure 2-8. Block diagram of transmitter final output stage

components of both waveguide and coaxial types, the functional discussion in the following paragraphs of the transmitter-exciter section of the transceiver will treat each of the four major components as subfunctional entities.

Double-Balanced Mixer (900 MHz CR30)

The double-balanced mixer CR30, used as the first element in the transmitter-exciter section, is electrically identical to, but slightly different in application from that used as the second mixer in the receiver front end. In this application, the mixer is used as an up-converter from 30 MHz to 900 MHz. To achieve this, the 5 MHz signal from the crystal controlled COHO oscillator (AAl) in the frequency synthesizer is sent from the operations van to the transceiver over coaxial cable. This 5 MHz signal is multiplied to 30 MHz by the switch/X6 frequency multiplier AA5 located in the transceiver. The 30 MHz is mixed in the double-balanced mixer CR30 with the second local oscillator signal. The resulting sum of these two frequencies is passed through the bandpass filter FL20 to reduce unwanted signals.

Bandpass Filter (900 MHz FL20)

The coaxial bandpass filter FL20 following the double-balanced mixer CR30 in the transmitter drive circuit passes only the sum frequency signals within the first intermediate-frequency passband to the medium power IF amplifier AR4. The filter is identical in function and performance characteristics to filter FL19 in the receiver front end.

Medium Power RF Amplifier (900 MHz)

The medium power RF amplifier AR4 provides a nominal 20 dB of amplification to the nominally 900 MHz first IF signal received from mixer CR30 and the following filter FL20. Amplification to about +10 to +15 dBm provides the power gain at the first IF required to drive the next up-converter which is X-band modulator A6. This signal contributes to the formation of the transmitter drive signal by driving the low frequency input port of the X-band modulator A6.

X-Band Modulator

The X-band modulator A6 functions as a filter/mixer in the transmitter circuit to sum the 900 MHz IF amplifier and first local oscillator signals to produce the X-band drive to the transmitter first stage TWT. The X-band modulator is mechanically identical to the first IF mixer in the receiver front-end except that the integral filter operates as the low-level output port 1 circuit, and the local oscillator input to port 2 is at a relatively high level of 35 mW compared to the first mixer input level of 4 mW.

X-Band Multiplier

The X-band multiplier consists of a combination of transistor and varactor stages with an input frequency range from 232-253 MHz which is multiplied to X-band with a bandwidth of 766 MHz. The input signal to the X-band multiplier originates in the frequency synthesizer in the equipment van, which is controlled by the computer. The X-band output signal is used for the first LO for both up- and down-conversion with a power level of approximately 20 to 70 milliwatts depending on the input frequency.

Addition of Pulse Compression

A pulse compression circuit is incorporated in the transceiver. The phase coding is performed at the 900 MHz first IF frequency to achieve sufficient bandwidth for fast switching. Because the transmitter transmits a one microsecond pulse burst, which is generated in the pulse-forming network (PFN), an 11-bit Barker code is used. As a result, each bit of subpulse in the phase coding is 90 nanoseconds wide, thus requiring a minimum IF bandwidth of 10 MHz for optimum matching.

Phase Modulating

The transmitter signal modulation to an 11-bit Barker code is performed at the 900 MHz first intermediate frequency followed by a mixer up-converter to translate the phase coded signal to X-band. This phase modulation process is similar to phase shift keying (i.e., biphase (BPSK)) where the two-phase position 0 and 180 degrees are denoted by the two binary states in the Barker code. The phase shift keying is done at the relatively high frequency first IF because of the ease of achieving the bandwidth necessary for rapid phase shifting to minimize group delay distortion which results in phase ambiguity.

For decoding, an 11-bit Barker code in the receiver is used to obtain pulse compression. The bipolar video "I" and "Q" from the quadrature phase detector are fed to a tapped delay line. This provides the matched filter to decode the 11-bit Barker code received from a point target. The taps on the delay line are connected so that the summed output reaches the maximum value when the proper code word is received from a point target from all ranges. This video is sent to an early/late gate for further processing.

Phase Coder Unit 139790

The phase coder unit consists basically of a shift register to read and write the Barker code, and several nand gates to perform the required logic functions.

The sign of an 11-bit Barker code is +++---+--+- where plus and minus arbitrarily represent 0 and 180 degrees phase, respectively. The 11-bit Barker code is generated in the 8-bit shift register during the readout period. Although the Barker code contains 11 bits, only 8 bits are written into the shift register since the first three bits (3 X 0.09 μsec) are in a normal carrier phase. Assuming that the 8 bits are read out correctly (in proper time sequence), there is no requirement to load the first 3 bits into the register.

The clock pulse generated is 0.099 μsec. It is the subpulse of the Barker code and is used to serially read out the 8-bit word from the shift register. The clock pulse is generated in the clock synchronizer. During the transmitter burst, starting with three clock pulses from the leading edge of the transmitter RF pulse, the remaining 8 bits are clocked out in a form of binary code from shift register Z1 and Z2. The initial three bits of the Barker code remain in a normal carrier phase, and therefore, are not read out of the shift register. A total of 11 bits binary phase, each 0.099 microsecond, will be contained in the 1.0 microsecond transmitter burst.

Clock Synchronizer 139794

A clock synchronizer is used in the transceiver to generate a 0.099 microsecond subpulse for the 11-bit Barker code. The frequency of this clock is counted down from the clock used in the system and is, therefore, coherent with the system clock. The output frequency of this unit is harmonically related to the system clock and the COHO signal. The clock synchronizer is gated on with the 5 MHz COHO, and is active only during receiver dead time. This prevents the harmonic of the output frequency (11.1 MHz) from the clock synchronizer from interfering with the 2nd IF echo and frequency synthesizer signal.

Receiver Functional Sections in the Transceiver

The circuits of the receiver functional section comprise what is termed as the receiver "front end" or "RF head" (see Figure 2-9). This section of the transceiver consists of several RF and IF components which perform initial RF signal conditioning and subsequent dual IF conversion functions. In this chain, the X-band signal is heterodyned down to 900 MHz, filtered, and mixed to produce the 30 MHz second IF which is routed by cable to the receiver-synthesizer in the instrumentation van. The following paragraphs describe circuits of the receiver functional section of the transceiver.

The recieved RF signals from the duplexer in the transmitter chain are routed to the X-band TR limiter where the incoming signals are limited to a maximum level compatible with the X-band RF amplifier and pass through the directional coupler, DC8, to the GaAs FET Preamp. Following amplification in the preamplifier, the signal proceeds through a high-pass, image-rejection, waveguide filter integral to the X-band balanced mixer, A5, which heterodynes the X-band signal down to 900 MHz. The 900 MHz first intermediate frequency is amplified by the IF preamplifier, AR2, (Figure 2-9), then bandpass-filtered by filter FL19 to remove images at the second mixer image frequency. Next, the signal goes to the 900 MHz, double-balanced mixer, CR29, to be mixed down to a 30 MHz second IF. The second LO signal input to the mixer occurs at the center frequency of 870 MHz. Following the second mixer, the 30 MHz output is sent by cable to the instrumentation van.

Significant characteristics of the receiver front end are as follows:

Type of receiver:	Dual-conversion, superheterodyne (single channel) with RF amplification
Type of RF amplifier:	GaAs FET preamplifier
Preamp noise figure:	3.9 dB
IF Bandwidth:	1.0 MHz 10 MHz with pulse compression

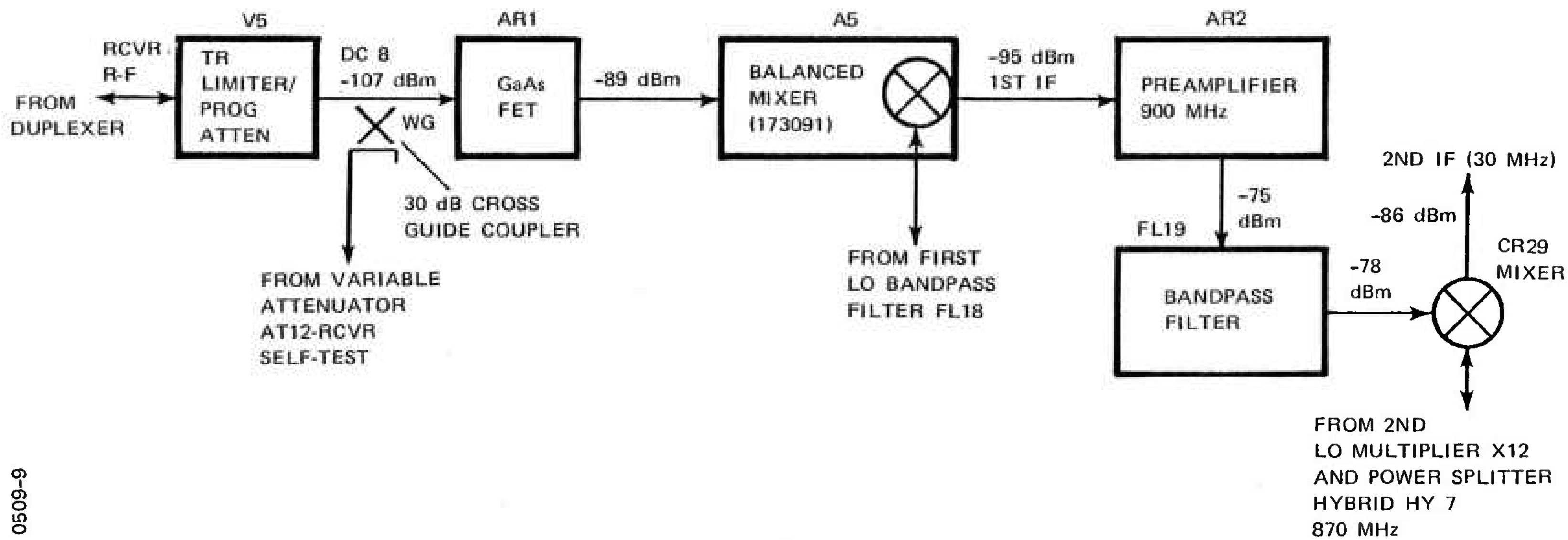

Figure 2-9. Receiver front end block diagram

Internal frequencies:	
Frequency synthesizer output:	232.8 to 25 MHz
First local oscillator:	X-band
Second local oscillator:	870 MHz
First intermediate frequency:	900 MHz
Second intermediate frequency:	30 MHz
Receiver dynamic range:	68 dB

X-Band TR Limiter

The X-band TR limiter functions to protect the X-band RF (transistor) pre-amplifier from damage from excessive RF input. The TR limiter consists of two parts combined in a single package. The input section of the device consists of a gas cell with a radioactive element to decrease ionization time and thereby to decrease the firing threshold level and a video diode circuit to bias the PIN diodes in the attenuator portion of the device during the transmitter pulse. This reduces spike energy leakage at moderate power levels. The second section is a solid-state programmable attenuator which constitutes the control element in the computer controlled gain adjustment/control network for set-up and AGC.

DIRECTIONAL COUPLER

The X-band directional coupler functions to provide a small sampling of RF energy, to self-test the receiver front end. The RF is coupled to the auxiliary arm of the directional coupler through a coaxial connector. Coupling attenuation is 30 dB, which accounts for insertion and coupling losses without requiring a correction factor. The signal level injected into the auxiliary arm is adjusted to approximately -60 dBm. The input signal level in the main arm to the GaAs FET amplifier is approximately -90 dBm.

X-Band RF Amplifier

The X-band GaAs FET pre-amplifier performs the function of low-noise RF preamplification to increase receiver sensitivity. The preamplifier, circulator and TR limiter precedes the high-pass, waveguide below cutoff filter that is integral to the X-band balanced mixer, A5.

X-Band Balanced Mixer

The X-band balanced mixer following the GaAs FET preamplifier consists of a waveguide balanced mixer coupled with a high-pass waveguide filter on the RF input port. The same type of filter/mixer is used in two places in the overall receiver system, serving two distinct functions:

1) Mixing local oscillator signals with the received RF to form a nominal 900 MHz intermediate frequency.
2) Mixing (summing) a 900 MHz signal with the local oscillator signal to form the X-band transmitter signal.

The mixer portion of the assembly is functionally similar to the "magic T" hybrid mixer. Due to balanced coupling of signal and LO inputs to the device, isolation between signal and LO ports is achieved as well as cancellation of LO noise in the resultant intermediate frequency output. The mixer is conventionally used in the receiver front end in that the X-band input signal is down-converted to the 900 MHz IF and delivered to the IF preamplifier, AR2. The input filter serves to attenuage image response and to reduce local oscillator feed-through.

IF Preamplifier

The solid state IF preamplifier, AR2, serves as the first IF amplifier providing the required interstage gain between the first and second mixers.

Bandpass Filter (900 MHz FL10)

The coaxial bandpass filter, FL19, following the IF preamplifier in the receiver front end, functions to pass all signals inside the first IF passband to the second mixer. The filter uses 1/4-wave coaxial elements as resonators. Capacitively loading the ungrounded ends of the resonator elements permits the use of physically shortened resonator elements. Coaxial construction of the filter yields improved temperature stability as compared to lumped constant construction. The high Q is necessary to obtain the required narrow bandwidth.

Double-Balanced Mixer (900 MHz CR29)

The double-balanced mixer, CR29, functions to produce a 30 MHz IF signal heterodyned down from the 900 MHz first IF frequency. The 900 MHz signal is mixed with the second local oscillator signal centered at 870 MHz, received from the X12 frequency multiplier, AR5.

The mixer is basically a broadband ring modulator matched to a 50 ohm input/output line employing four hot carrier diodes (Schottky barrier junction type) characteristically performing as low noise, resistive elements. Close matching of the diodes of the hot carrier type provides an excellent noise figure at the 900 MHz frequency, with superior port-to-port isolation. Mixers of the same type and application are used in the frequency synthesizer circuits in the equipment van, except they are used in a dual-stage, up-converting mode.

Synthesizer Functional Section in the Transceiver

This section describes those RF circuits in the transceiver which develop the transmitter drive and receiver local oscillator frequencies. (See Figure 2-10.) Synthesizer circuits function to generate frequencies that precisely control the azimuth scan of the radar. These circuits are distributed between the transceiver and the frequency synthesizer in the van and are functionally integrated although physically separated. Descriptions of circuits in the van which cover the digitally-programmed generation of selected control frequencies originating in the frequency synthesizer modules in the equipment van are presented later in this section.

The transceiver first LO derives its signals from the frequency synthesizer signal sent from the van via cable. The input signal to the X-band frequency multiplier, AR3, is the sum frequency of three-step oscillator frequencies which have been multiplied (X3) and amplified. The X-band frequency multiplier raises the power level of the input signal, multiplies the frequency by a factor

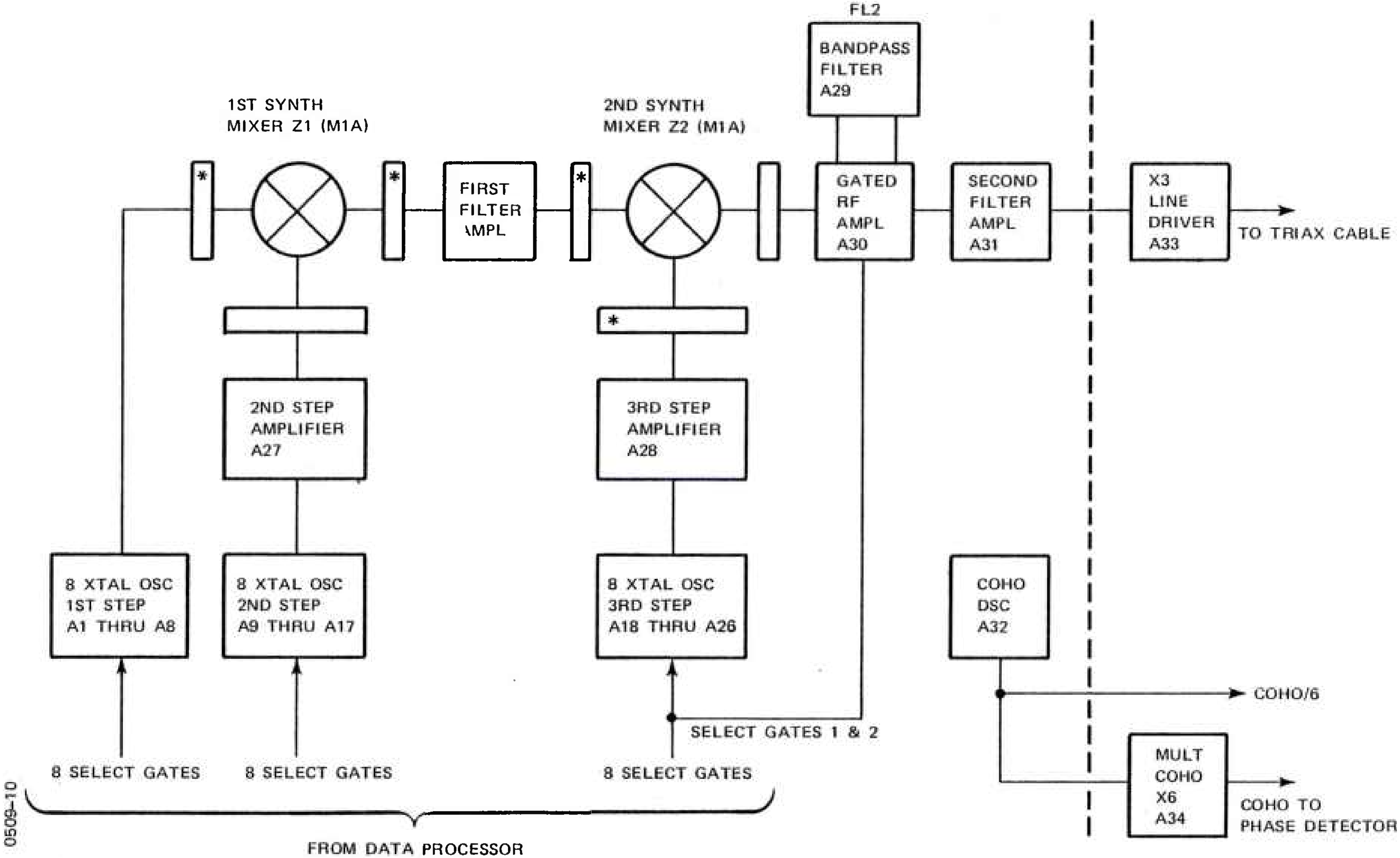

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Figure 2-10. Synthesizer block diagram described in the next paragraph, provides local oscillator drive to the first receiving mixer, and drives the last (X-band) up-converter which completes the frequency translation of the transmitter drive signal. Additional circuits described in subsequent paragraphs are the X-band frequency multiplier, and second local oscillator chain.

X-Band Frequency Multiplier

The frequency multiplier module converts the frequency synthesizer output to X-band to provide the first LO to down-convert in the receiver mixer and to up-convert in the X-band mixer modulator.

COHO Circuitry

The 5 MHz signal from the COHO oscillator in the frequency synthesizer assembly is transmitted to the transceiver at one-sixth (COHO/6) its final frequency. In the transceiver, the 5 MHz signal is sent to the switch/frequency X6 multiplier, AA5, located in the transceiver where the signal is first amplified, then multiplied to 30 MHz. The resultant 30 MHz signal is turned on by the COHO control gate (from timing generator No. 3) to provide an output to drive the up-converting UHF mixer, CR30, described in the transmitted-exciter functional section. The level of the 30 MHz output signal is set by a control on the switch/frequency X6 multiplier.

Receiver Second Local Oscillator Chain

The oscillator modules, located in the transceiver generate the basic receiver second local oscillator frequency. The output of the oscillator is connected to multiply the frequency of the active oscillator by twelve in the X12 frequency multiplier, AR5. Sufficient gain is available to deliver 5 to 10 milliwatts output at 870 MHz. The output of the X12 frequency multiplier is equally divided by a coaxial hybrid, HY7, and then each signal is bandpass-filtered. One output passed through bandpass filter, FL21, is applied as the second local oscillator signal to the receiver. The other output is passed through bandpass filter, FL22 (same type as FL21 above), and serves as the local oscillator signal for the up-converting (900 MHz) mixer in the transmitter drive chain.

2.1.4 Power Conversion

The ARBAT Specification requires operation from either commercial three phase lines or from a local power generating set. Power conversion is required for the ARBAT Transceiver only because of its original design application to minimize size and weight for a high degree of transportability. Redesign of the units power supplies would have entailed additional costs for magnetics and packaging as opposed to the retention of the original magnetics and configuration and the inclusion of a power frequency converter. A rotary converter was selected rather than a solid state unit for cost reasons only.

The converter generator (Georator Corporation Model No. 39-001) supplied in the ARBAT Systems is a permanent magnet rotor brushless design which is controlled (output) by the inclusion of control windings to the stator. The output is three phase 120/208 volts (4 wire) continuous duty or 120 volts delta line to line. Output voltage may be manually adjusted by means of an external control ± 5% at no load and at full load. Greater control of the output by means of this control is possible at partial loading. Generator output return to regulated state following a departure caused by an instantaneous transient (application or removal) is 250 milliseconds. The maximum dip in voltage output as a result of applying full load from a no-load condition is 10%, whereas the maximum rise in output on removal of full load to no-load condition is 5%. Generator output frequency stability is ± 1/2% at a constant input frequency. Maximum frequency variation under loading conditions is: No load = 420 Hz; Full load = 410 Hz. The converter temperature rise is rated at 50° C (generator and motor). The generator section is driven by an integral low slip induction motor (3 phase input) rated for continuous duty.

A summary of the prime operating specifications are listed in Table 2-II.

The rotary converter selected and installed in the ARBAT systems met all requirements and has provided fully adequate service since installation and operation to the time of this report. Maintenance requirements have been consistent with the systems availability requirements. The few requirements for maintenance to date have been a result of semiconductor failure in the voltage regulation circuit included in the unit.

Table 2-II. Power Converter Operating Parameters

OUTPUT						INPUT			
kVA	Volts	Regulation	Phase	Freq.* No Load	Freq.* Full Load	Motor	Volts	Full Load Current (Amps)	Noise
5	120/208	± 1.5%	3	420	410	7.5 HP 3 Phase 60 Hz 1760 rpm	220/240 ± 10%	21.1/10.5	79 dB at 3 ft. (ASA STD. No. Z24.7 - 1950)

0509-26

* The actual load placed on the prime power buss varies depending on the transmitter pulse repetition rate and to a very small degree on the high voltage control adjustment. The current value shown represents the maximum current level under any operating condition.

2.1.5 Transport Vehicle

The transport vehicle is a custom fabricated wheeled vehicle designed to transport the antenna subsystem during movement of the system and to serve as the stable mounting platform for the antenna at the selected operating location.

2.1.6 Dehydrator

This unit supplies dry air under low positive pressure to the antenna arrays and waveguide elements within the transceiver to prevent condensation and surface damage or water collection which would produce severe VSWR problems and power losses.

2.2 INSTRUMENTATION (VAN) SUBSYSTEM

The ARBAT Systems operations (Table 2-III and Figure 2-11) van provides an operating area which houses the radar control equipment, portions of the radar receiver circuitry (2nd IF) and detection circuitry, signal processing and data computation/processing/display/assemblies with recording facilities and a rotary 60 Hz to 400 Hz three-phase power converter to supply 400 Hz power to the transceiver located in the Antenna Subsystem. All operating and on-site analysis functions are performed by personnel in the van. In addition to the latter, equipment and space is provided for the display of operator console display data at a remote (rear of van) CRT terminal for visitors. Space and cabinets are provided for storage of magnetic tape supplies, printer tape and related supplies. A work table for operator use as a desk is provided at the end of the van opposite the operator console. Van environmental control/conditioning is provided by air conditioning/heating units in the van.

2.2.1 Van Subsystem Functional Allocations

Radar control functions in normal operation (as opposed to test mode operation) are controlled by a general purpose computer in response to operator commands. The "operator/machine" interface is via a standard computer terminal keyboard and an alpha/numeric/graphic CRT display located in the operator console. In normal system operation all operator functions (excluding Prime Power Control and tape replacement, etc.) are accomplished at the Operator Console. A Radar Control Panel is located in close proximity adjacent to the operator Console permitting the operator to access the transmitter Standby/Radiate switches and antenna radiate/servo disable interlock switches during breaks in test firing, or as required for safety reasons. To facilitate system calibration, testing and to facilitate maintenance, all normally computer controlled individual functions may also be accomplished manually by operator/maintenance personnel at the Special Purpose Processor (SPP) Maintenance Panel and Antenna Test Set. Any individual command may be entered into the system by means of thumbwheel switches. Series of different control commands may be entered in any order sequentially. In addition to the latter, the basic control functions such as transmitter radiation, standby, BITE reset, transmitter Local/Remote control selection and radiate/servo (antenna) disable interlocks are only operable manually at the Radar Control Console. Figure 2-12 shows the relative positions of the major equipment items. Prime power control for the Instrumentation van, including the 400 Hz power converter required for the radar transceiver is a function of the Power Distribution and Switching Panel located in the rear portion of the van.

2.2.2 Receiver Functional Elements

The IF processing circuits comprising the receiver functional section provide the filtering, limiting, envelope detection, and phase detection of the 30 MHz IF signal arriving at the van via cable. From the 30 MHz input, one normal video output and one quadrature bipolar video output are produced from the phase detector. The IF amplifier stages are all wideband, fixed tuned with no tuning or alignment required after initial adjustment. The bandwidth of the receiver circuit is established in the bandpass filter A1 located in the IF processing assembly. The following paragraphs describe circuits of the receiver functional section contained within the IF processing unit. A block diagram of the 2nd IF and IF Processing units is shown in Figure 2-13. The bipolar video channel consists of two separate phase detectors with the COHO signal fed 90 degrees out of phase in one

Table 2-III. Instrumentation/Operations Van

The Instrumentation Van subsystem includes the vehicle proper, operating elements (consoles, recorders, printers, data processors, etc.) and portions of the radar receiver, BITE items and ancillary items. All of the latter are described in the appropriate detail sections of this report.

Size:	
Length (outside)	25 ft
Width (outside)	119.25 in.
Height (road surface to top unladen)	137.5 in.
Gross Weight with equipment:	14,000 lbs
Axles:	2 Tandem, 7000 lbs gross each
Tires:	9.00 X 14.5 - 12 ply Rating 3230 lbs loading each.
Construction:	
Chassis	steel welded
Body (exterior)	aluminum
Walls:	3 inch polyurethene foam filled; density 2 lbs/cubic ft
Window:	Single pane, tinted safety glass with removable exterior cover.
Running Lights:	12 volt ICC seven pin connector
Doors:	2; one door located in each side wall on opposite ends of body.
Floor Opening:	(2) 4 X 10 ft between horizontal rails at 6 ft and 7 ft dimension and (2) 4 X 10 ft. openings between horizontal rails at 13 ft and 14 ft Splash proof covers for floor openings are provided on underside of van.
Equipment mounting holes	drilled and topped holes per DWG 160332 Sheet 3.
Air Conditioning:	
Cooling	92000 BTU capacity
Heating	18 kW, thermostatically controlled with manual setting and override.
Accessories:	
Reflectors -	ICC approved
Brakes -	Electric per ICC regulation
Tow bar -	Lunette ring for pintle hook up.
Tredowns -	4 rings; one at each lower corner.
Supports -	4 leveling jacks

0509-27 (1 of 2)

Table 2-III. Instrumentation/Operations Van (Continued)

0509-27 (2 of 2)

Accessories: (Continued)	
Benches -	2; bench supports fastened to floor of rear and bench tops secured to wall at rear of bench.
Lighting (instrument) -	Lighting to be incandescent recessed per drawing 160332. Overhead fixtures 1 through 4, 5 through 8 and 9 through 10 to be on separate circuits, and each circuit to be provided with dimmer controls.

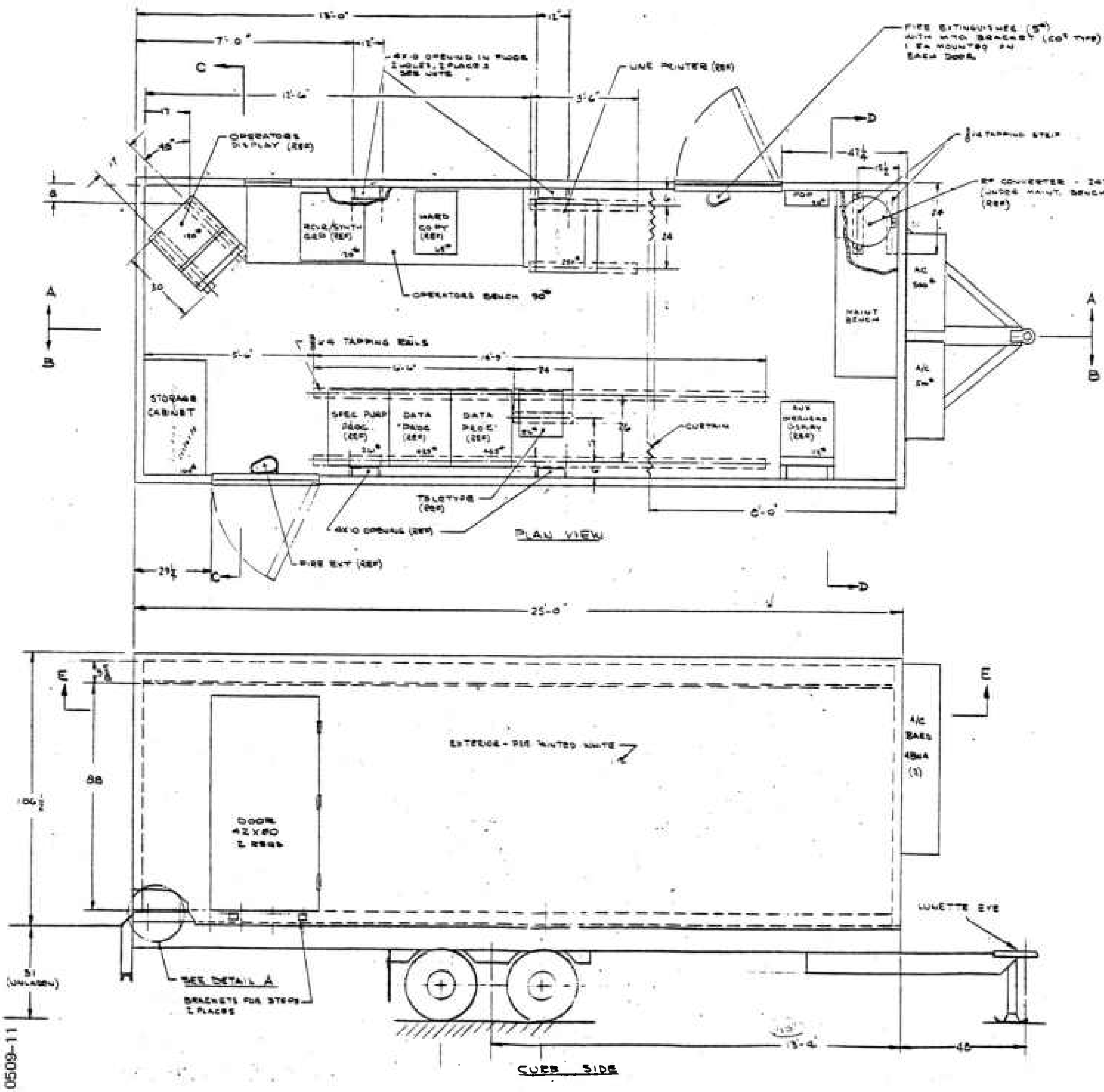

Figure 2-11. ARBAT instrumentation van design

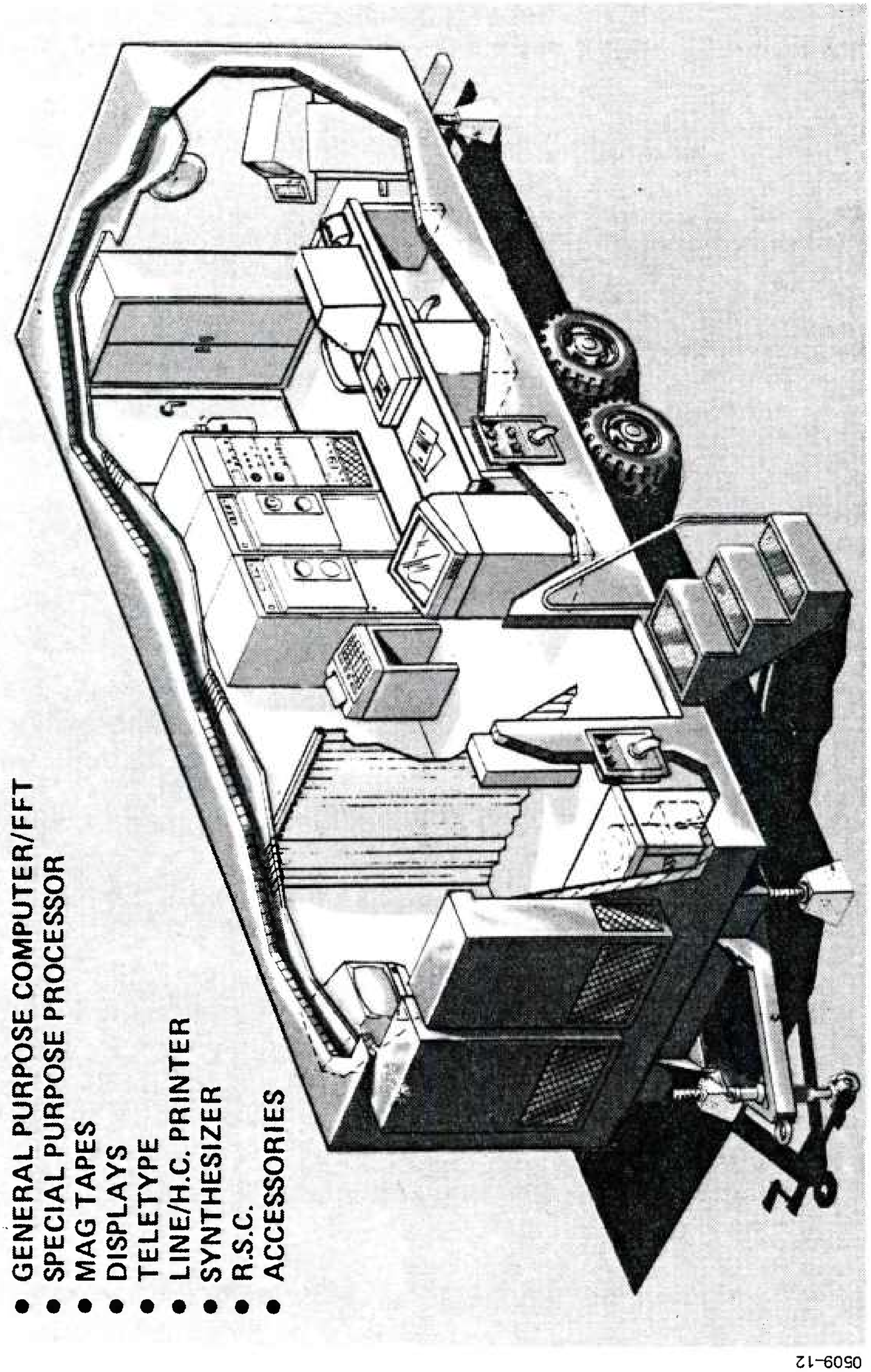

Figure 2-12. ARBAT instrumentation van layout

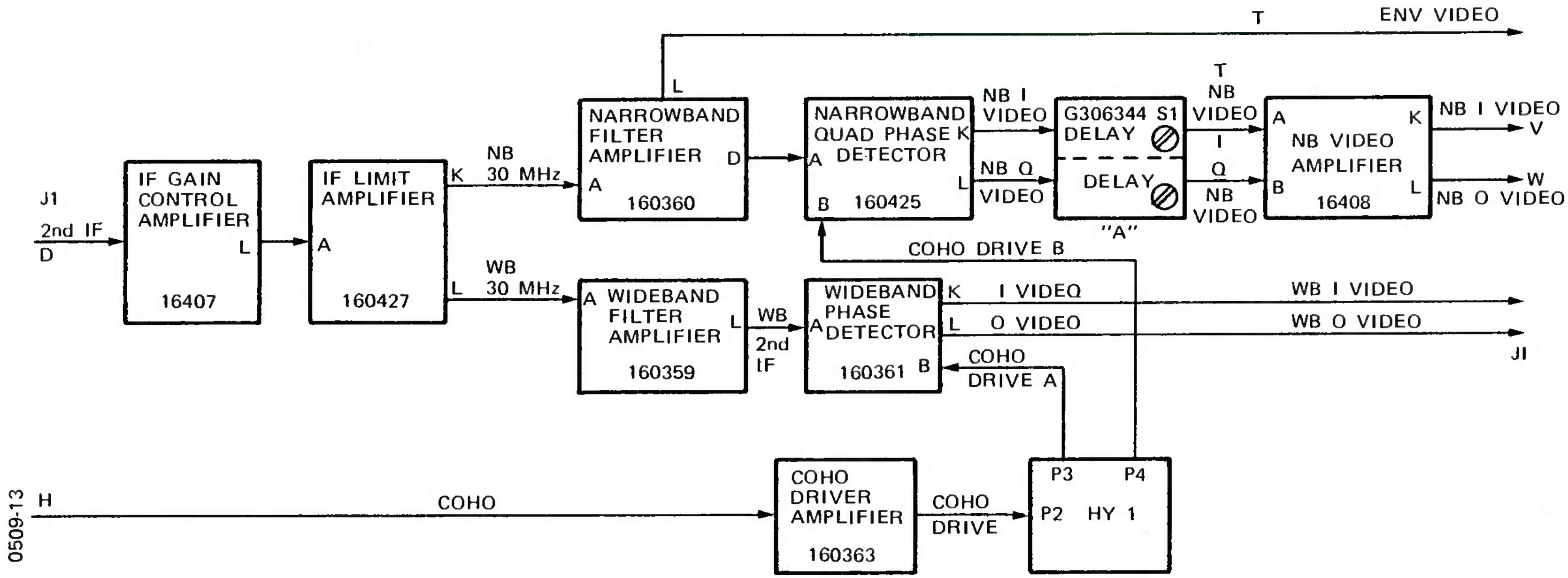

Figure 2-13. Receiver IF/video elements contained in instrumentation van

channel with respect to the other. The 30 MHz IF signal is fed to both phase detectors in phase. As a result, the bipolar output voltage of one phase detector will be 90 degrees out of phase with respect to the other detector resulting in the "I" and "Q" outputs. The phase detector and its associated IF amplifiers and circuits are designed to minimize the intermodulation (IM) product generated in the phase detector. This is accomplished by proper limiting of the IF amplifier to avoid overloading the double balance mixer which is susceptible to IM products. These IM products appear as 2nd, 3rd and higher order harmonics of doppler frequencies. If the rain spectrum extends beyond the zero doppler frequency, the higher order IM products may fall in the desired doppler pass-band which will impair the capability of the clutter rejection provisions and appear as excess clutter residue. The quadrature phase detector is capable of holding all IM products down in excess of 50 dB regardless of the level of the 30 MHz IF signal. This assures that under any condition of return signal there will be no significant IM products generated in the phase detector to degrade MTI performance.

Reference drive to the phase detector is the COHO 30 MHz. The normal video output is obtained by passing the second portion of the IF signal through an amplifier to the envelope detector. A linear law detector extending over a 30 dB range is employed for the target tracking function of the radar set.

The pulse compressor unit is an all range analog 11-bit Barker decoder. It follows a wideband quadrature phase detector. Two identical units are required for both I and Q channels following the quadrature phase detector.

A block diagram of the IF amplifier-pulse compressor is shown in Figure 2-14. The pulse compressor unit contains a multiple tapped delay line and a differential amplifier. The delay line is provided with 9 taps. When a signal with a Barker code is applied to the tapped delay line with taps spaced at intervals of the subpulse width, the polarity of each output tap is positive or negative in accordance with phase code of the signal. A tap having positive polarity is summed and fed to the non-inverting differential amplifier while all negative polarity taps are summed and fed to the inverting side of the differential amplifier. The output of the differential amplifier is summed, the 11-bit Barker code decoded and pulse compression performed for further video processing.

2.2.3 Synthesizer Functional Elements

The synthesizer circuits function to generate the base frequencies needed to precisely control the azimuth scan of the radar and to provide the signals required to develop local-oscillator frequencies in the receiver front end. Although the functionally integrated synthesizer is physically distributed between the antenna subsystem and the instrumentation van subsystem, this section describes the synthesizer circuits in the equipment van. The basic synthesizer is a digitally-programmed device capable of rapidly selecting a control frequency which, after providing for certain functions in the receiver front end, produces the radar transmitter output over its frequency range in incremental steps. The modules and sub-units comprising the synthesizer functional section consist of twenty-four step frequency oscillators, two step amplifiers, two mixers, a gated RF amplifier, a power monitor circuit, a COHO oscillator and several bandpass filters. Thumbwheel selector switches are

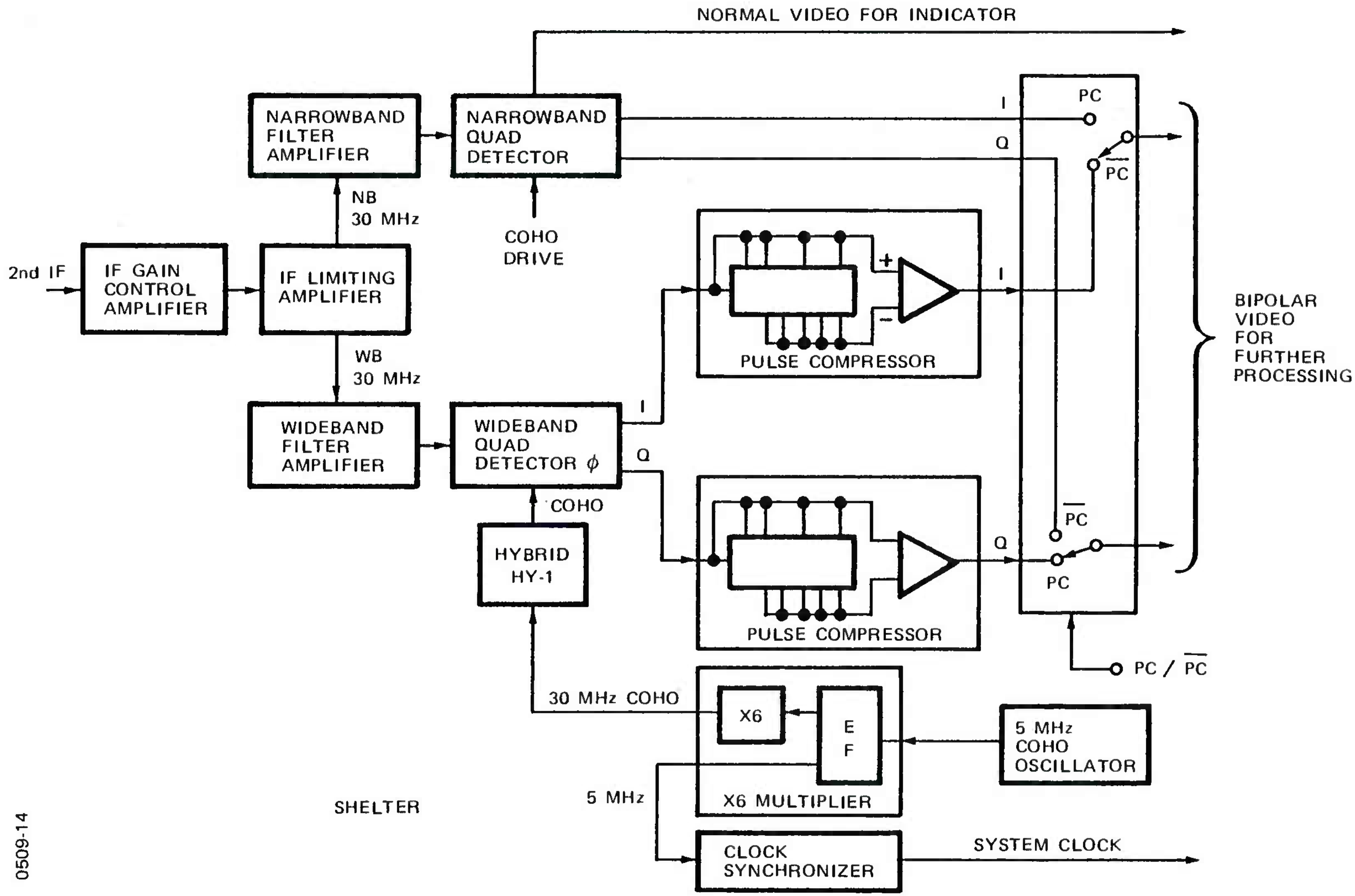

Figure 2-14. Simplified IF amplifier pulse compression block diagram

provided on the Special Purpose Processor Maintenance Panel (SPPMPL) that permit manual selection of any available output frequency as a BITE feature.

Fundamentally, several frequencies are mixed to synthesize the desired frequencies. The theory of operation is similar to that of commercially available synthesizers, except that this unit operates with an octal number system for digital programming convenience. The output frequency of the synthesizer is established by digitally-controlled solid-state switching that selects from various combinations of frequencies. The output frequencies of the synthesizer are as high as practical in order to maintain a low multiplication ratio following the synthesizer and thus diminish spurious responses in the multiplication process.

The crystal-controlled COHO oscillator, A34, generates a 5 MHz signal intended for use as the system COHO, and is distributed to perform additional functions in the system. One 5 MHz output, multiplied by 6 (to 30 MHz), is used as a reference signal for the phase detector of the envelope/phase detector amplifier. The COHO signal also provides the reference signal to the envelope/phase detector.

A total of twenty-four step frequency oscillator modules with on/off switching amplifiers are connected in three banks of eight each. These modules are composed of 1st step frequency oscillators A1 through A8, 2nd step frequency oscillators A9 through A17, and 3rd step frequency oscillators A18 through A26. The outputs in each bank of eight are commonly connected, however, only one oscillator in each bank has its output gated "on" at any given time. Gating of each oscillator output is effected by one of the twenty-four logic lines originating in the data processor programmer. The 1st, 2nd, and 3rd step frequency oscillator banks, respectively, operate at low, middle and high frequencies, and provide small, medium and large increments of frequency preceding the mixing operation as described below.

The synthesizer circuits employ two double-balanced mixers of the same type used in the receiver front end. These mixers are composed of the first synthesizer mixer Z1 and the second synthesizer mixer A2. The two mixers perform up-converting and are designed to combine the various amplified outputs of the step frequency oscillators to produce the sum frequency of any three selected step frequency oscillators. The mixing operation is explained by first noting that the outputs of all the 1st step frequency oscillators A1 through A8 are directly connected to one input of the first synthesizer mixer. Outputs of the 2nd step frequency oscillators A9 through A16 are first amplified by the 2nd step amplifier A27 to raise their level to about 20 mW before going to the other input of the first synthesizer mixer. The output of the first synthesizer mixer is directed to the first filter amplifier module where a bandpass filter and amplifier selects the sum frequency of the 1st and 2nd step frequencies, which then is used as one input to the second synthesizer mixer. The 3rd step frequency oscillator A18 through A26 outputs, like the 2nd step, are amplified in the 3rd step amplifier A28 to provide proper mixer drive level and are then directed to the remaining input of the 2nd synthesizer mixer. The output of the 2nd synthesizer mixer is then bandpass filtered and amplified for selection of the sum frequency. This is now the sum of the three selected step oscillator frequencies. The sum frequency is multiplied (X3), amplified and sent via the cable to the transceiver where it eventually reaches the X-band frequency multiplier for further up-converting.

The gated RF amplifier A30 and its associated bandpass filter FL2 function between the 2nd synthesizer mixer and Z2 and the 2nd filter amp A31 to reject the lower order modulation products generated in the 2nd synthesizer mixer when the synthesizer is operated at the low end of the band. In order to reject synthesizer spurs which cannot be adequately attenuated by a single filter as in the case of FL1 following the 2nd synthesizer mixer, a gated RF amplifier and bandpass filter combination is used. Filter FL2 is gated on only when the synthesizer is operating at the low end of the band. When the synthesizer frequency is required to operate at the high end, the gated RF amplifier switches filter F2 out and thus the gated RF amplifier simply becomes a bandpass amplifier. This is automatically accomplished by feeding the proper programmer select gate into the gated RF amplifier. Since two select gates from the 3rd step frequency oscillator are fed to the gated RF amplifier, the circuit operates to make filter FL2 effective during the 3/8 frequency range at the lower end of the scan while during 5/8 of the upper end of the band filter FL2 is bypassed.

The Special Purpose Processor (SPP) performs a key function in the ARBAT System in that it provides the logic interface between the two subsystems comprising the ARBAT System as well as the interface between major assemblies within each subsystem where applicable for both operational and BITE functions. Providing the interface between the Eclipse GPP and itself (SPP) which in turn interfaces with the remainder of the ARBAT system constitutes a prime task allocated to the Special Purpose Processor. The latter interfacing functions are provided by circuitry fabricated on common commercial board types, the Data General Purpose Interface Boards which are located in the Eclipse GPP rack. While these assemblies are, organizationally more a part of the SPP than the Eclipse GPP, they are physically located in the latter and are described separately.

The SPP, in addition to its interface functions contains two major BITE assemblies, the SPP Maintenance Panel (with BITE Monitor Logic Board) and the Antenna Test Set. The SPP rack, in addition to the logic circuits required for interfacing the system and the two units provided for BITE, contains separate power supplies for all assemblies located in the rack that require dc power. In addition to the above assemblies, the SPP rack also contains two commercial oscilloscopes. One of the two oscilloscopes is provided as a "A" scan display for monitoring envelope video and other signals accessible on the SPP maintenance panel and on the Antenna Test Set. The second oscilloscope is intended for use as a beam position display.

The SPP functions are provided by the assemblies described in the following paragraphs.

The Gated Video Converter (GVC) accepts normal or pulse compressed I and Q channel video which is gated integrated, and converted to ten bit data in offset binary format. Gating is accomplished by a split gate (near and far) of width determined by the video selected. Provisions for multiplexing both I and Q PC and non-PC are included in the GVC circuitry. Since the conversion to digital form is accomplished on a time multiplexed basis, the four gated and integrated video signals require provisions for holding each signal until the appropriate time in the conversion period.

The Range Timing Logic Board provides timing triggers, gates and clocks required in the SPP internally and externally throughout the radar. The following timing signals are generated or processed within the RTU.

SPP Clocks:	22.22 MHz, 11.11 MHz, 5.55 MHz and 2.77 MHz
System Triggers:	Triggers distributed throughout the system are derived from a range counter initiated from the 22.22 MHz clock. Duration of PRT is controlled by the GP interface circuitry.
Start-Track Trigger:	Initiated at a GP defined range count (45 msec granularity)
Reference Range Mark:	Used for "A" scope calibration.
Reference Frame Turning signal:	For GP I/O data transfer function.
Real-time Clock:	For GP timing.

The Input/Output Control Unit (IOCU) controls the transfer of track command words from the Eclipse GPP to various functional areas in the following assemblies; Range Timing Unit, Radar System Interface Unit, Input Data Control Unit and the SPP Maintenance Panel. In addition to the above destinations, the IOCU controls the transfer of data between sources in the GVC, RSIU, RTU, BITE monitor, SPP Maintenance Panel and the IOCU. Other functions outside the realm of operational data transfer are also performed by the IOCU in the area of system BITE.

The Radar System Interface Unit holds time and buffer data messages between the SPP Data Bus and other data users which is in six data categories as follows:

1) NOVA output Data which includes:
   - Antenna Position Command
   - Receiver Gain (attenuator control)
   - Phase Command (Phase Shift Control)
   - Frequency Command (Synthesizer Control)
   - Display X-axis
   - Display Y-axis
2) NOVA Input Data including the following:
   - Antenna Position
   - Antenna Temperature
3) Gunfire Sensor: This function provides a signal to the NOVA Interface indicating a gunfire signal from a remote sensor or switch closure. Reset of the circuit is accomplished by a Gunfire Reset signal generated in the IOCU.
4) Input Signals
   - Antenna Temperature
   - Data Strobe
   - 2.77 MHz Clocks
   - SPP Bus Data

- SPP Bus control
- RMAX - 1 cp
- RMAX
- Beam 1 lobing select (odd PRT's)
- Beam 2 lobing select (even PRT's)
- End of Frame
- Input Data Strobe

5) Output Signals
   - RSIU Error
   - Antenna Data Transmission Error
   - Antenna Position Command
   - Command Strobe Antenna
   - Receiver Gain
   - Phase Command
   - Frequency Command
   - Frequency Command Strobe
   - Display X Axis
   - Display Y Axis

6) BITE
   - Antenna position parity test
   - SPP bus test (NOVA control).
   - Analog Output Test

The BITE Monitor Logic (BML) board provides for an interface between the SPP Maintenance Panel and BITE data sources. The function includes monitoring and collecting BITE data, display of bus data on the Maintenance Panel and at other locations as required. In addition to the latter functions the circuits provide the capability for modification of NOVA output data for display on the Maintenance Panel BITE display. The BML performs the following specific functions:

- Storage and display of selected SPP bus NOVA input and output data.
- Loading and transfer of NOVA output override data to the IOCU.
- Collection, storage and display of system BITE and SPP BITE errors.
- Determines antenna Performance Line (PML) error from the PML signal received at the Antenna Test Set.
- Serves as the buffer/interface for error indications sent to the Radar Control Console.

The following specific signals are interfaced in the BITE Monitor Logic Board:

Input Signals

BUS SIGNALS	
TB3999-A	Data Bus
GN4999-A	I/O Select
SM4000-20	Shift Gates
2.77 MHz Clock	RTU
D8430, Bias BITE	ATS
D8431, PML BITE	ATS
F1300, End of Frame	RTU
System BITE Signals	
Servo Data Parity	RSIU
ANT, Bias Supply Error	ATS
Servo Command Parity	ATS
RF Group	Receiver/Synth
SPP BITE Signals	
RTU ERROR	
IO IOCC ERROR	
RSIU ERROR	
GVC ERROR	
Gunfire (Remote)	

Output Signals

Gunfire	To IOCU

BITE

Bus registers can be tested under NOVA control

Two prime functional requirements are provided by the Data General Interface Boards, although each prime function contains multiple sub-functions. The two prime functions are described briefly.

a) The Output Data Channel Interface Unit (ODCIU) permits track command words generated by the general purpose data processor (Data General Eclipse Computer) to be output and entered into the SPP. When this function is accomplished, the Eclipse GPP outputs a track command starting address and a word count to the ODCIU, which informs the Input Data Channel Interface (IDCIU) Unit when the loading function is completed. The IOCIU then requests track command words individually until all track command words generated in the Eclipse GPP have been transferred to the SPP via the ODCIU.

b) The Input Data Channel Interface Unit (IDCIU) Functions basically parallel those of the ODCIU described above, except that the direction of transfer is from the SPP to the Eclipse GPP. The circuitry in the unit permits the transfer/input of digitized video and other signals from the SPP in format and time compatible for input to the GPP. To function, the GPP loads a starting address and a word count into the IOCIU after which the IOCU transfers the data into the Eclipse GPP via the IDCIU. At the end of the transfer function the IOCU terminates the function with an interrupt. A block interface diagram showing the overall functional relationships is shown in Figure 2-15.

The Eclipse General Purpose Computer is a commercial Data General Eclipse computer Model 230 with the following options:

a) 64K word semiconductor memory (two DG8602 32kW MOS memory banks with automatic memory error checking and corrections).
b) memory allocation and protection (MAP)
c) hardware floating point processor (DG8413)
d) expansion chassis (DG8914)
e) disk interface board (DG6045)
f) TTY controller board (DG4077)
g) AP-to-NOVA interface board
h) SPP interface boards (two DG4040 GPI with the DG4012 Data Channel)

The GP computer group is used to perform the execution of the ARBAT Radar Control Programs to interface with the peripheral equipment in a manner to provide data input, output, and control, and to perform numerical calculations in support of required analysis requirements.

The Array Processor of the ARBAT Data Processing Subsystem consists of the Floating Point Systems, Inc. Array Transform Processor AP-120B with the following options:

a) 512 words of RAM program storage memory
b) AP-120-DMF8 8K fast data memory
c) 2048 word standard table memory

The processor is a high speed, highly accurate floating point processor used to perform mathematical computations. The high speed computations are performed using pipe line hardware. This type processor is efficient with algorithms involving matrix and vector operations such as the test Fourier Transform. The AP receives initial control from the Eclipse GPP or GPC and then operates independently controlling its own input/output and execution.

The Array Processing Group is used to perform certain mathematical computations for the ARBAT Radar Control Program. In particular, it performs all the signal processing algorithms concerned with the parameter measurement phase of the real-time tracking mode of operation of the ARBAT Radar Control Program.

The Magnetic Tape Group consists of the Model 5091 Tape Transport Controller with the manually switchable 800/1600 BPI option and two Bright Industries Model 2700 Tape Transports.

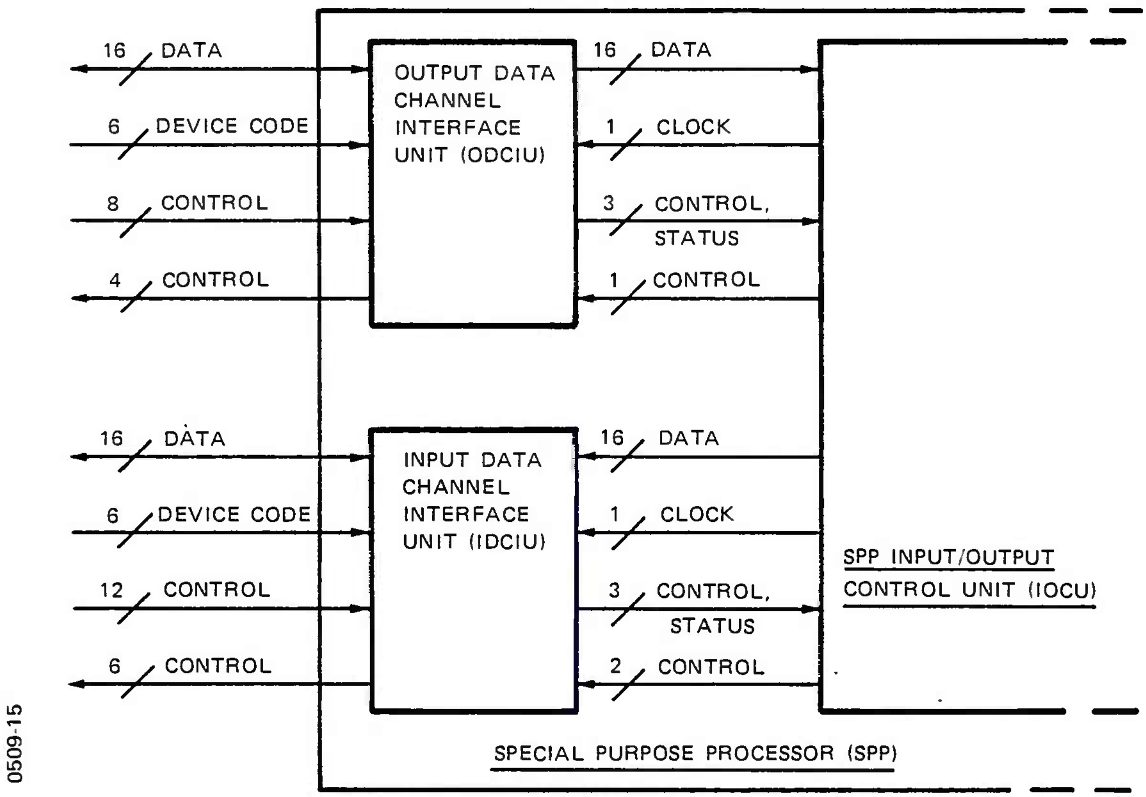

Figure 2-15. General interface diagram, Nova GPP/Nova I/O boards

They are a nine-track, 125 inches per second, Digital Magnetic Tape Transport capable of a data transfer rate of 100K words per second, using phase encoding of the digital data. One tape transport operates at 1600 BPI and the second transport is manually switchable to either 1600 BPI or 800 BPI.

The Magnetic Tape Group records the detailed data acquired by the system along the trajectory. Transport No. 1 records the detailed raw data, radar commands, the trajectory state vector in radar coordinates, and (under the Operations Option) the results of a set of subcalculations which occur during a frame of operation. One frame of operation occurs at a minimum every 2.5 milliseconds during the Track State. Transport No. 2 is capable of recording the overflow from Transport No. 1. During the Post Analysis State the transports are able to read the detailed and summary data tapes recorded earlier and record a newly created summary data tape. The summary tape will consist of a set of summary data representing the state vector components in gun coordinates averaged along the trajectory at 50-millisecond intervals.

Both the detailed and summary data tapes are recorded in the following format:

a) Radar Data Base - a record block consisting of 3840 16-bit words containing all of the information contained in the global data base at the start of the tracking mode.
b) Track Data - a set of physical blocks of 3840 words containing all of the track data.
c) EOF mark
d) EOF mark

Items a, b, and c are recorded for each trajectory on the tape. Item c consists of enough blocks to record all the data derived from a trajectory. Item b consists of either 20 subblocks of 192 words for the detail tape or 96 subblocks of 40 words for the summary tape. This format requires that all tapes terminate with a double EOF.

The disk system is a Data General Model 4236 cartridge disk drive and controller. It has 5 Mbytes of removable storage (disk cartridges), and 5 Mbytes of fixed storage with a data rate of 312,500 bytes/sec. Head positioning time ranges from 8 msec to 70 msec with a latency time of 12.5 msec. Currently, the ARBAT system consists of nine disk cartridges which allows for 45 Mbytes of off-line disk storage.

The disk system is used to store large files of data for the ARBAT Radar Control Program during its non-real time usage. It is used primarily for:

1) Real-Time Disk Operating System Routines
2) Both source and load modules of various ARBAT Radar Control Programs Procedure Options.
3) Control Line programs to perform the various compiling, assembling, loading, execution, and program listing printings.
4) General storage of user files.

The disk system is controlled by the RDOS operating system during software maintenance state ARBAT Radar Control Program operation. During the real time operation the disk system will not have IO operation.

The line printer is a Potter Instruments LP6351. This is a 132 column and 500 lines per minute impact printer using a 5 x 7 dot matrix uppercase character format.

The Line Printer Group is primarily used during the Software Maintenance State for print-out of assembler and compiler listings. In the system maintenance state, the printer will be used for the output of the system diagnostics and data base listing. In the Analysis State, the line printer is used for printer dumps of the detailed and summary data.

The Display Terminal consists of a Tektronix Model 4014-1 Computer Display Terminal, a Model 619 Remote Display, a hard copy unit, Model 4631 and various options and interfaces. The Remote Display is a graphics slaved storage screen which provides an identical display to the Model 4014-1 Display Terminal (operating console). The Display Terminal consists of an operator's keyboard and a graphics storage screen. The Display terminal has the write through and buffer refresh option which allows a small amount of information to be displayed and selectably erased on the screen of the display.

The keyboard of the Display Console is used as Operation's Console during the Operator interaction subtasks and as an Operator interrupt generator during the operation of the program. The Operator interaction subtasks use a line of the bottom of the Display Terminal Screen for the Operators Console Display. The remaining portion of the Display is used for the Data Display Function of the various System Operation Modes. During the operation of RDOS Library routines such as the editor, loader, compilers, and debug programs the entire display screen is used for operator input/output as they were originally designed.

The Teletype Group of the ARBAT Radar System Data Processing Subsystem consists of a teletype terminal, a real time clock (RTC), and their associated controllers. The teletype is a standard ASR 33 teletype operating at 10 characters per second (110 baud). The real time clock generates an interrupt at a program selectable rate. The RTC frequencies available are the line frequency (60 Hz), 10 Hz, 100 Hz, and 1000 Hz.

The Teletype Group provides a means to control the RDOS Operating System during the operation of the ARBAT Radar Control Program. The teletype is used for keyboard and paper tape input and output while the RTC is used to provide time-of-day updates and timing control to RDOS. The Teletype Group is not used during the operation of the ARBAT Radar Control Program.

2.3 SOFTWARE SUBSYSTEM

The software subsystem consists of five categories of software which are used to control all aspects of the ARBAT Radar System's Operation. These five categories are:

1) Track
2) System Maintenance
3) Summary Processing
4) Analysis Programs
5) Software Maintenance Routines

The Track Program and the System Maintenance Program actually are executed by the same real time program. The difference consists only in the Operator selected execution mode, the modules to be executed, and the target to be tracked. The Summary Processing Software consists of a single program which is used to convert the detail data tape into a summary data tape and to perform an impact prediction for the trajectory. The Analysis Software consists of three off-line programs which are used to present the detail or summary data to the operator graphically, via the display terminal, or in a tabular form, via the printer. The Software Maintenance Routines consist of software provided by Data General, and Floating Point Systems, that is used to develop, maintain, and execute software and of control line routines developed by ITTG to simplify the control of the software maintenance operations.

2.3.1 On-Line Program - "Track"

The on-line program consists of one program which currently satisfies both the need for a program to track the projectile and a program for system maintenance to test both the hardware and software subsystems operation. The software is discussed in terms of a set of subprograms which may be conveniently differentiated by their required functions. These subprograms are subdivided into a set of tasks corresponding to the various functions. In some cases these tasks are reduced to subtasks and the steps to perform the task or subtask. The software structure is the same for both the projectile track and system maintenance down to the subtask level. At the subtask level the structure differs depending upon the differences between the various projectile track modes and system maintenance tests. The processing involved with the execution of the projectile track programs consists of several modes of operation involved with the search, acquisition, tracking, and reacquisition of the target. The processing involved with the execution of the system maintenance consists of several tests operating within the same program structure to test the hardware (servo, sweep, and raster, and manual control tests) and software (scatter and projectile track, with subcalculation output, tests). The software modules corresponding to the differing modes and tests are called "cases" and are executed via a set of jump tables based upon an operator input case selection for the tests or upon a mode selection variable indicating the case for the projectile track operation.

The purpose of the projectile track program is to initiate and maintain a track on a target while recording on the detail tape the raw data, radar commands, and processed data to provide information concerning the target's trajectory. Concurrent with the trajectory track and data recording, the program shall provide the operator with a real time display of selected trajectory information so that the operator may make an immediate determination as to the success of the current test.

A high level diagram of the program structure necessary to accomplish this purpose is illustrated in Figure 2-16. The program structure consists of the following six parts:

a) operating system
b) initialization
c) output processing
d) summary processing
e) track loop control
f) termination

The operating system is a task oriented operating system which controls the tasking sequential execution, most IO operations, and the software maintenance environment before and after program execution. The ARBAT Radar System utilizes the operating system called RDOS supplied by Data General Corporation and optimized for the ARBAT data processing configuration and requirements.

The Initialization Subprogram inputs the track specification data, converts that input into radar control commands, and prepares the software and hardware subsystems for the upcoming track. The track procedure is initiated by the Initialization Subprogram by outputting to the SPP its initial radar commands and transferring control to the Output Processing Subprogram.

The Output Processing Subprogram is a control loop which passes control to the Summary Processing Subprogram, the real time output display operation, and the Termination Subprogram when the need arises for these activities. During the execution of the Output Processing and Summary Processing Subprograms, the SPP will cause a string of data compilation interrupts (approximately once every 5 milliseconds) indicating that the operation of the previous frame has been completed and the new frame is starting. The interrupt processing routine consists of the Track Control Loop Subprogram.

The Track Control Loop Subprogram processes the raw radar data from the previous frame to command the radar functions of the next frame and to form an estimate of the previous frame trajectory variables for detail data recording and ensemble smoothing process for the Summary Processing Subroutine.

The Summary Processing Subprogram processes the trajectory information smoothed over a 50 millisecond interval in the radar coordinate system into position and velocity information in the gun coordinate system for the real-time graphic display and to initiate the real-time impact prediction function at the onset of the Termination Subprogram.

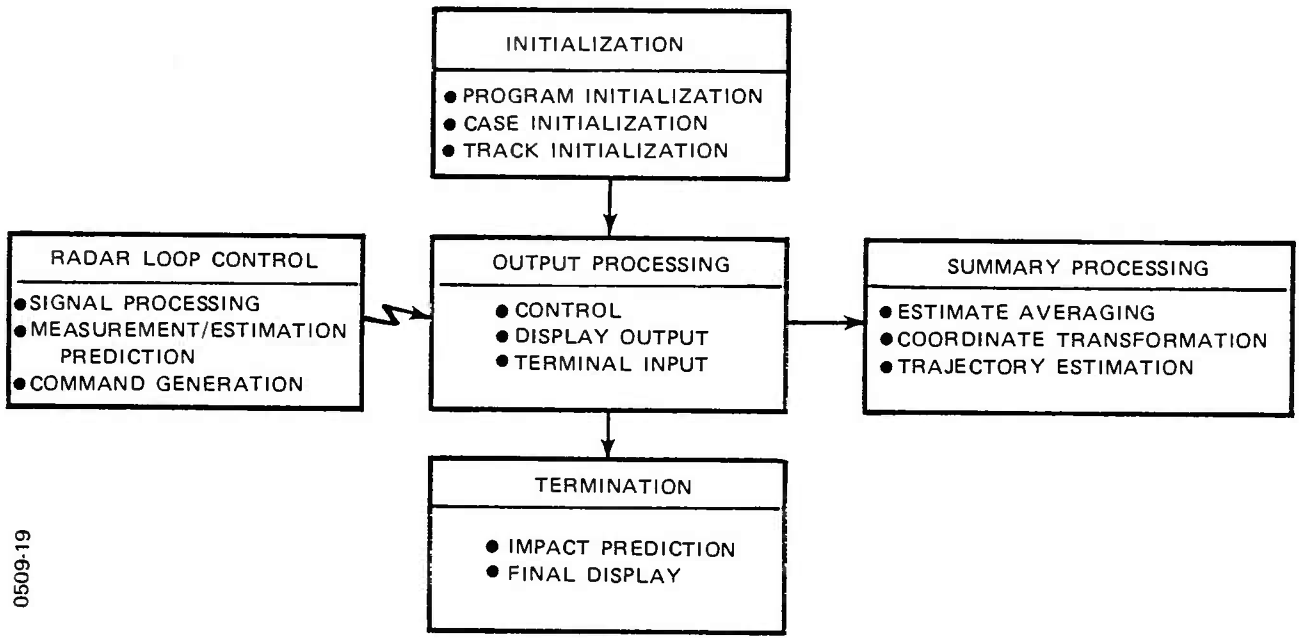

Figure 2-16. ARBAT track program software structure

Upon a decision to terminate the track by either the operator or the Radar Track Loop Control Subprogram, the program control passes to the Termination Subprogram which closes the tracking and data recording activities and then performs a real-time impact prediction of the target.

2.3.1.1 Initialization Subprogram - The Initialization Subprogram prepares the ARBAT Radar System for the forthcoming projectile track. The Initialization Subprogram may be considered to be composed of the following tasks:

a) Program Initialization
b) Case Initialization
c) Track Initialization.

To initialize the program the following steps are executed:

1) the initial overlay is opened and set
2) the interrupt structure is set
3) various program variables are set
4) the realtime IO options are selected by the operator.

Once the program has been initialized in the Program Initialization Task the program operation is specified in the Case Initialization Task. The main function required of the Case Initialization Task is to set the program execution for the test selected by the operator. For the selected test this involves the possible selection of test parameters, modification to the Radar Data Base, calculations to specify the search mode, gate position and initial radar commands, and a display of the results. These functions are illustrated in Figure 2-17 specifying the processing flow of the Case Initialization Task. Initially, the operator is presented with the choice of tests he wishes to perform. The choices are:

1) Track
2) Scatter
3) Sweep
4) Manual Radar Control
5) Raster
6) Rectangular
7) Ramp

The selection of a particular test specifies the "case" which will be processed. The choice of the Track test will initiate the particular search "case" corresponding to the input target variables.

Once the test case has been specified the task requests the input data unique to the test in order to specify the test parameter. The track, sweep, and scatter tests expect additional data to be entered to the task to specify the search locations. In the Track test all target data is required. In the Sweep and Scatter tests only the parameters not specified in the sweep/scatter initialization

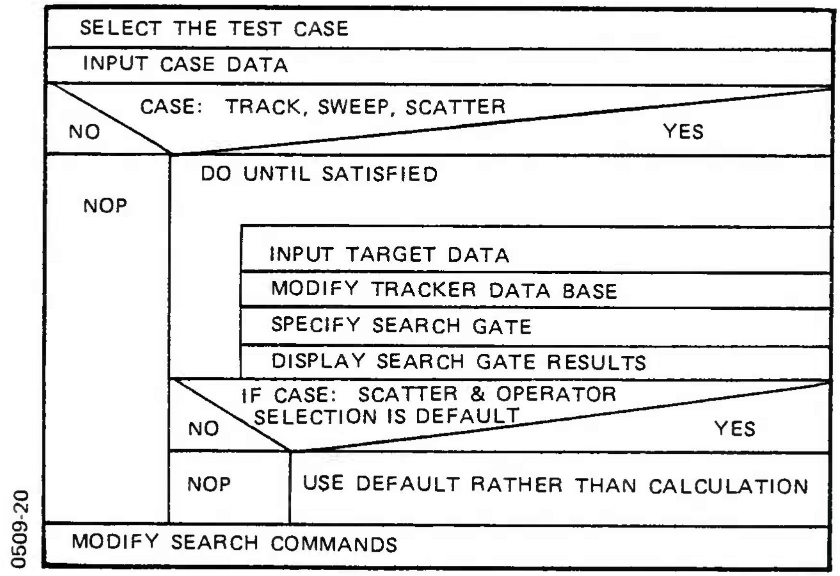

Figure 2-17. Case task initialization

are required. The input data entered consists of target parameters and Radar Data Base Variables involve tracking and system variables. This data is optionally entered via the keyboard corresponding to a set menu or as default variables compiled into the program via a definition routine called SITEID.

The task target information menu is presented to the operator to set/modify the following input Projectile Data:

1) Test Name
2) Projectile Type
3) Summary Data Base Name
4) Firing Site ID number
5) rcs
6) QE Angle
7) Bearing Angle
8) Muzzle Velocity
9) Intercept Time
10) Request To modify Radar Data Base
11) Specific impact prediction parameters (ballistic coefficient, weight, diameter, ground height).

The default values are preset in a routine called SITEINIT which was formed earlier by the Operator. This routine sets all default values for all possible sets of firing site ID and all parameters in the Radar Data Base. The selection of a new firesite by the operator will reset the Radar Data Base Variables and constants and initialize the corresponding projectile default values. Table 2-IV contains a tabulation of the Radar Data Base variables and constants which may be reset by the operator using this menu sequence. Once the input variables are set, the task performs a set of calculations to obtain the parameters necessary to set the search gate position and radar search operation. The search calculations are performed in the following steps:

1) Convert firing site information into radar coordinates.
2) Calculate the target velocity vector at the firing site.
3) Using the intercept time calculate the search gate position, expected Doppler velocity, and angular rates.
4) Using these parameters specify the search gate pattern - beam offset, lobing coordinate, and requirement for the picket fence.
5) Calculate azimuth beam, elevation beam, servo, and minimum elevation beam positions.
6) Convert this data to beam numbers and transmitted frequency.
7) Calculate the expected signal strength, aspect angle, and Doppler frequency.

The input and search variables used in this calculation are tabulated in Table 2-V. The search parameters are displayed to the operator for further examination. If the operator is satisfied, he continues the software execution by using the search parameters to set the various tracking loop variables and calculating the actual search commands. The radar search commands are also specified in Table 2-V.

Table 2-IV. Radar Variables Changeable by Initialization Menu

Radar Data Base

Antenna Position (north, east, height).
Azimuth Reference (servo reference, az bias, az midscan).
Elevation Reference (tilt angle, el bias, el midscan).
Range Reference.
Firing Site Position (north, east, height).
Measured Power.
Receiver Gain.

Track Variables

Servo Tracking Constants (alpha, beta).
Signal Tracking Constants (signal alpha, signal residue alpha).
Doppler Tracking Constants (alpha, beta, residue alpha).
Azimuth Tracking Constants (3 sets: alpha, beta, residue alpha).
Elevation Tracking Constants (3 sets: alpha, beta, residue alpha).
Range Tracking Constants (2 sets: alpha, beta, residue alpha).
Doppler/Range residual alpha.
Threshold (search, tracking).
Miss Count maximums (search, track, reacquire).
Minimum PRT
Search Pattern (lobing sequence, az offset).
Track Center Offset (az, elevation).
Azimuth (position, rate, residual).
Elevation (position, rate, residual).
Range (position, rate, residual).
Purged Filters (high, low).
Servoed position (rate).
Minimum elevation (beam, angle).
Flags (pulse compression, range/Doppler coupling).
Signal (level, frequency).
Clutter Level.

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Table 2-V. Initialization Search Calculation Parameters

Input Variables	Search Parameters	Search Commands
Target rcs	az beam number/angle	az beam number (2)
Target Muzzle Velocity	el beam number/angle	phase commands (2)
Gun QE Angle	Range	range gate position command
Gun Bearing Angle	Servo position	range gate size command
Gun Position	Doppler Velocity/Frequency	PRT command
Intercept Time	Search pattern	frame control commands
Radar Position	received signal strength	servo position command
Clutter Level	minimum el beam number	AGC command
Receiver Gain	az, el rates	
az, el, Range, Servo Bias Angle	aspect angle	
Antenna Tilt	Doppler freq /velocity rate	
Transmitted Power Level	initial signal frequency/wavelength	
Minimum el angle		

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The Track Initialization Task prepares the program execution for the real time radar control modes of program operation involved with the Output Processing, Summary Processing, and Radar Loop Control Subprograms. To perform the "Track Initialization Task", the following subtasks are performed:

1) initialize static graphics
2) initialize the magnetic tape by recording the data base as the initial file record
3) bring on the real-time overlay
4) initialize the Array Processor
5) initialize the realtime display graphic output and terminal input
6) initialize the SPP and send a set of two radar commands to specify the entered servo position and antenna temperature parameters.
7) start the output processing loop

2.3.1.2 Output Processing Subprogram - The Output Processing Subprogram controls the execution of the summary processing and display operations during the real-time trajectory track. Figure 2-18 provides a simplified diagram of the operation of the Output Processing Subprogram. The Output Processing Subprogram performs the following tasks:

1) fire signal processing. When a real or simulated gun fire signal has been received
2) keyboard input processing
3) summary processing
4) display processing
5) display output

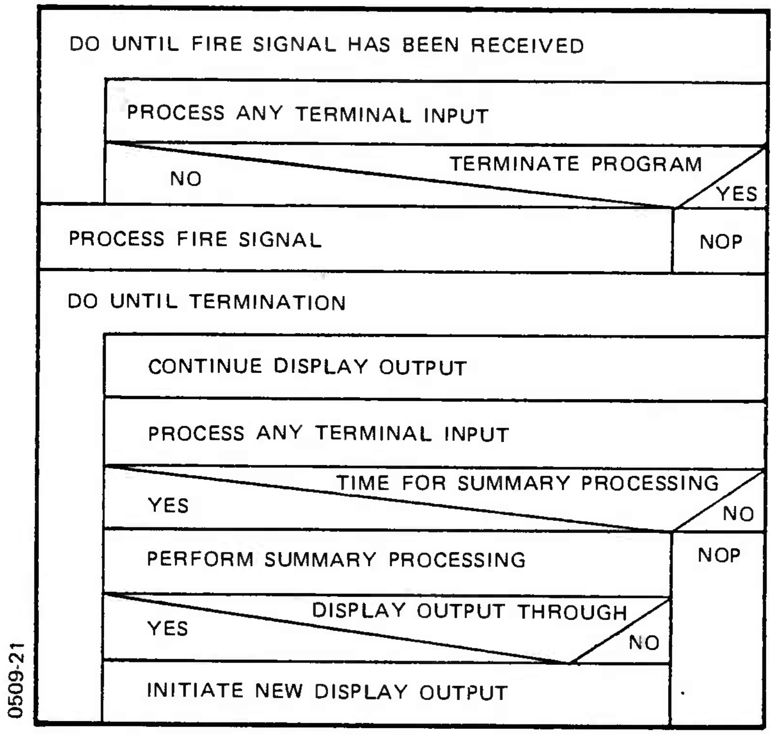

Figure 2-18. Output processing subprogram

The initial task of the Output Processing Subprogram is a simple loop to continually examine for the display input characters to simulate a projectile firing interrupt. Once the fire interrupt has been received (simulated by the input characters on the display or a real relay closure interrupt from the SPP), the Subprogram initiates the radar operation by sending to the SPP the initial double buffered search radar command. Once the initial search radar command has been sent to the SPP, the Output Processing Subprogram execution is in the form of a continuous background loop performing the remaining tasks. Initially, the loop examines for a request for termination of the background loop (and track termination) by examination of messages from the following sources:

1) a frame number counter has counted down to zero.
2) the operator has input a "control D, 5" character string via the display input.
3) the "Track Control Loop" Subprogram has detected a track termination.
4) console switches 7, 8, or 9 on the Eclipse have been raised.

If either of these messages have been received then the Output Processing Subprogram is terminated and the Termination Subprogram processing is initiated. If termination is not requested then the summary processing task is started. If the time elapsed since the previous transfer of control to the Summary Processing Subprogram is greater than 47 milliseconds, then the Summary Processing Subprogram processing is completed. The next task performed is the display processing task which converts the summary data obtained over the previous 1 - 2 seconds into a buffer of display buffer commands for output to the real time display. This output display is in the form of graphics (height vs range, velocity vs range, and signal energy density in each filter vs the filter number) and alphanumerics of the track information. This output display buffer is output several times during the execution of the Output Processing Loop and the Radar Control Loop Subprogram.

2.3.1.3 Summary Processing Subprogram - The Summary Processing Subprogram is the processing associated with supplying the real-time display processing task with gun coordinate trajectory data smoothed over a 50 millisecond interval. This Summary Processing Subprogram is not to be confused with the summary processing in the analyses program "Summary" whose function of producing the Summary Data Tape is discussed later in Section 2.3.2. The Summary Processing Subprogram performs the following tasks:

1) calculates the smoothed data in radar coordinates from the sum of the individual frame trajectory data,
2) converts the smoothed data from radar coordinates into gun coordinates,
3) estimates the gun coordinates position, rate, and acceleration using an α - β - γ least square error estimator filter,
4) calculates the total velocity using the estimated coordinate rates.
5) converts the range, height, and total velocity data into a form compatible with the display processing.

2.3.1.4 Radar Control Loop Subprogram - The Radar Control Loop Subprogram is made up of the set of routines which control the ARBAT Radar System, gather data from the radar system, and processes that data into further radar commands and trajectory information. The Radar Loop Control Subprogram is in the form of an SPP interrupt handler. The processing is initiated by an input data completion interrupt sent by the SPP to the Eclipse GP when the final data word of the previous frames input from the SPP to the Eclipse has been sent. The processing of the Subprogram is completed after a new radar command for the following data frame has been sent to the SPP. After the interrupt has been received, the Radar Control Loop Subprogram initiates processing by performing the normal interrupt processing of clearing the interrupt and saving the background processing parameters.

The actual Radar Control Loop processing then proceeds according to Figure 2-19. The Signal Processing Task is immediately initiated. This Task is performed entirely in the Array Processor using its pipeline structure to take advantage of the vector and matrix manipulation required. The following steps are performed in the Signal Processing Task:

1) transfer of video data to the Array Processor,
2) time weighting of the video data system,
3) spectral analysis using four sixteen point complex FFT's,
4) energy calculation,
5) incoherent averaging to form the signal, near and far, and first and second lobe spectra.
6) "Greatest of Filter Pair" processing, and,
7) verneer calculation,
8) transfer of vernier and filter map data to the Eclipse.

While the Signal Processing Task is being performed in the Array Processor, the Eclipse is initiating the data recording activity, if the data recording briefer is complete and sending display data to the display terminal.

After receiving indication that the signal processing calculations have been completed, the processing continues with the Measurement Task no. 1. This task is composed of the following steps:

1) Updating subbuffer and frame counters;
2) separate the discrete SPP input words into proper Data General formatted words;
3) calculate the measured signal, clutter, and residual energy levels;
4) correct the signal energy level for saddle losses due to the signal placement within the filters, lobes, and range gate;
5) perform the frame time and servo position measurements and estimates.

The result of this task is the data necessary to form the criteria for the hit/miss detection decision in the Case Processing Task. As seen in the Figure 2-20, the Case Processing Task is composed of the following set of subtasks:

1) signal detection
2) measurement no. 2
3) miss processing
4) estimation

INTERRUPT PROCESSING
SIGNAL PROCESSING TASK
MEASUREMENT No. 1 TASK
CASE PROCESSING TASK a. SEARCH b. ACQUIRE FRAME 1 c. ACQUIRE FRAME 2 d. ACQUIRE FRAME 3 e. FIRM TRACK AZ LOBE f. FIRM TRACK EL LOBE g. REACQUIRE h. SCATTER TEST i. RASTER TEST j. SWEEP TEST k. SERVO TEST l. MANUAL RADAR CONTROL
RADAR COMMAND TASK

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Figure 2-19. Radar loop control subprogram

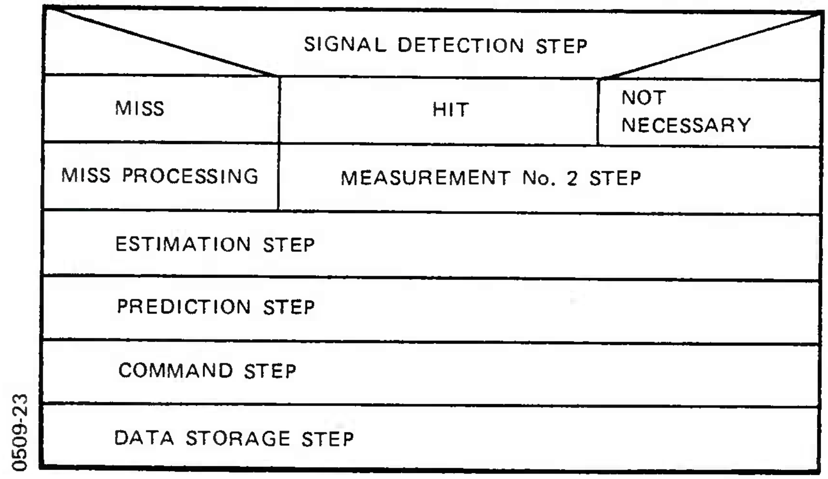

Figure 2-20. Case processing case description

5) prediction
6) command calculation
7) data storage

The processing performed in each of these subtasks is dependent upon the "case" being processed. The case is determined by the following:

1) test selected by the operator (track, ramp, rectangular, sweep, manual radar control, scatter, or raster test);
2) the real time "mode" of operation (search, acquire, firm track, or reacquire);
3) the frame pattern (frame number, lobe selection).

The actual case possibilities are tabulated in Figure 2-19 and identified in Table 2-VI. For each case the subtasks shown in Figure 2-20 may be the same, similar, or completely different from the subtasks of the other cases or maybe completely missing. A simplified indication of which subtasks are performed by which case is shown in Table 2-VII. The following section gives a brief summary of the steps involved with each subtask.

Detection - The detection subtask makes the decision whether enough signal energy in the current data frame was present to declare that the target was seen during the frame and with a sufficient s/n to update the estimate of the trajectory parameters, (a hit) or should the current estimate be based upon an update of previous estimates. A CFAR detection criteria is used for the detection subtask

Table 2-VI. Projectile Track Processing Case Definitions

Search (az/el)	Mode of operation to search for the target in a fixed search gate position along the expected trajectory using a fixed measurement lobe and range gate at two differing PRT frequencies designed to avoid blind specks.
Acquisition (az/el, 2,3 lobe)	Mode of operation to acquire the target after detection in the search mode through a sequence of three preselected measurement and command frames.
Firm Track (az/el)	Mode of operation to maintain a track on the target while estimating the targets position.
Reacquire	Mode of operation to re-acquire a track of a target after it was lost. Operation similar to search mode except the search gate position is, based upon a prediction of the target previous state vector.
Manual Radar Control Test	A fixed radar command is sent to the SPP to control the system in a manner selected by the operator. Used to move the antenna to a fixed position.
Servo Rectangular Test	Test to force the servo command to a new position via a step command, maintain that position for a period of time, and step to another position. Used to test the servo subsystem for maximum angular velocity, acceleration, and overshoot.
Servo Ramp Test	Test to force the servo command to follow a sequence of operator input ramps. This test is used to verify requirement compliance and to set the servo feedback gain.
Raster Test	Test to force the azimuth and elevation commands in a sequence to force the antenna beam to follow a rectangular raster pattern.
Scatter Test	Test designed to help debugg the software tracking loop characteristics. The test allows the operator to have each of the tracking loops (range, az beam, elevation, servo position, AGC, prt) operate independently in either a closed loop (command based upon the measurement/estimate) or open loop (command preselected by the operator). The search position for both the open or closed loop operation may be selected to be based upon preselected radar parameters or on input target parameter (normal input menu).
Sweep Test	Test designed to sweep the tracking loop commands independently between preselected terminators and at any given rate. This test allows the analyst to measure various properties of the Radar system (beam pattern, transmitter/frequency phase stability, verneer vs measurement properties, etc.).

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Table 2-VII. Subtask Requirements by Case

Subtasks	Search (az/el)	Acq 1	Firm Track (az/el)	Reacquire	Scatter	Raster Test	Servo Test	Manual Radar Control
Detection Subtask	X	X	X	X	X			
Measurement								
freq (ambiguous)	X	X		X	X	X		X
freq (unambiguous) vel			X		X			
lobe	X	X	X	X	X	X		X
servo/time	X	X	X	X	X	X	X	X
range	X	X	X	X	X	X		X
Miss processing			X		X			
Estimate			X		X			
Prediction			X	X	X			
Command			X		X			
Special command	X	X		X	X	X	X	X

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based upon the ratio of the measured signal energy (corrected for saddle losses) to the residual energy formed by the ensemble average of those filters not containing either the signal or clutter time averaged in a low pass filter formed by an alpha filter. The value of the ratio greater than a given threshold indicates a hit, otherwise, a miss occurred. The threshold value during the firm track mode differs (is lower) than the value used during the search, acquire, and reacquire modes of the projectile track and scatter tests.

Measurement Subtasks - The Measurement Subtasks converts selected radar and signal processing data into parameter measurements. Table 2-VIII illustrates the conversion of the input variables into the measurement parameters. The measurements made by case is indicated in Table 2-VII. During the acquire mode the measurement is determined by the az/el pattern used in search.

Estimation Subtasks – The Estimation Subtask provides an estimate of the measurement parameters according to the type of tracking filter specified in Table 2-VIII. In both the α and the $\alpha - \beta$ filters the estimate is for both the first order term and the rate. In the α filters the rate is estimated from an α - filter of the rate of change of the first order estimate. All α - β filters are changed to α filters for small values of rate estimates. During the acquire mode, there is no estimation subtask.

Table 2-VIII. Measurement/Estimates Parameters

frequency vernier				α slow	
PRT	ambiguous freq	unambiguous freq	velocity measurement	α, β fast	
xmitters freq					meter/sec
range vernier				α slow	
range gate position	range measurement			α, β fast	
range gate seq					meters
lobe vernier				α	az beam number
az lobe separation	azimuth beam position				
az lobe position					
loop				α large sep	el beam number
lobe vernier				α, β small separation	
el lobe sep	el beam position			α small, slow	
el lobe position					
filter signal energy				α	milliwatts
saddle losses					
AG command	signal energy				
receiver gain					
previous frame time	current frame time				milliseconds
time elapsed					
servo position	servo position			α, β	degrees

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The initial estimate of the rate in the tracking filters is as specified in the initialization Subprogram. All estimate parameters have a low pass track on the residual between the prediction and measurement which is used for track quality measurements and control of the range gate size and beam separation. The az beam is always tracked using a α filter. The elevation beam estimation uses an α-β filter for the small lobe separation and α filter for the large separation. The range position is estimated using an α-β filter.

Miss Processing – During the firm track mode the Miss Processing Subtask performs the following tasks:

1) estimates the parameters from the previous first and second order terms;
2) updates the residual estimates;
3) updates the miss counter and determines whether the firm track mode should be terminated from the search or reacquire modes.

Prediction – Using the current estimate a prediction is made for all measurement variables. This is performed only in the firm track and reacquire modes for all variables except the servo parameters which are predicted for all cases.

Special Commands – All of the radar commands for the servo test, manual search and acquisition test, radar control, raster, cases and part of the commands for the scatter test and reacquire cases are calculated from operator input data by special algorithms rather than the target prediction based upon previous measurement and estimates of the tracking parameters.

Command Subtask – The Command Subtask uses the tracking loop parameter predictions to calculate the command of the next frame. To calculate the radar command frame the predicted loop parameters, the following steps are performed:

1) range ambiguity and pulse group definition are set;
2) range, azimuth, elevation, servo counters are out from predicted position;
3) frequency ambiguity and prt are set from transmitted frequency and predicted values;
4) set lobe separation and range gate based upon residuals;
5) calculate the required AGC to maintain a constant signal level into receiver;
6) set all commands.

The Termination Subtask performs the following subtasks necessary to conveniently end the program processing.

1) initialize the termination overlay;
2) write final data buffer in the detect tape;
3) perform an impact prediction;
4) write termination data to the display;
5) close the IO files;
6) terminate the program.

2.3.2 Off Line Summary Processing Program

The Summary Processing Program takes as input a file from a detail data tape and produces as output a file on a summary data tape. It also performs an impact prediction on the trajectory. The Summary Processing Program is totally independent from the Summary Processing Subprogram described in Section 2.3.1.3, although there are some identical tasks performed. The summary Processing Program performs the following tasks:

1) Calculates the smoothed data in radar coordinates from the sum of the individual frame trajectory data.
2) Converts the smoothed data from radar coordinates into gun coordinates.

3) Estimates the gun coordinates position, rate, acceleration, and mean square residual using a least square error estimated filter.

4) Calculates the total velocity using the estimated coordinate rates and total mean square residual using the coordinate residuals.

5) Calculates the drag by removing the gravity effects and aligning the acceleration components along the velocity vector of the center of gravity.

6) Outputs results of tasks 1-4 above to magnetic tape.

7) Perform impact prediction using ballistic integration and output the result to the CRT display.

2.3.3 Off Line Analysis Programs

There are three separate programs available for analyzing the data collected on mag tape. One allows the operator to graph variables from the detail data tape onto the Tektronix display terminal, another does the same for the summary data tape, and the third allows the operator to selectively print and format data from either the detail or summary tape onto the high-speed printer.

2.3.4 Software Maintenance Routines

All of the ARBAT software described in 2.3.1 through 2.3.3 are maintained under Data General's RDOS (Real-time Disk Operating System) on the Eclipse computer system. The following is a list of Data General Software used to create and maintain the ARBAT software:

1) CLI (Command Line Interpreter): interactive control language

2) Superedit: interactive editor

3) Eclipse Macro Assembler

4) Fortran 5 Compiler

Section 3

SYSTEM OPERATION

Section 3

SYSTEM OPERATION

3.1 FUNCTIONAL OPERATION

The overall functional block diagram is shown in Figure 3-1. Connection of the antenna to the transmitter and receiver is made by means of a duplexer. Functionally, the transmitter is a pulsed amplifier using the output of the frequency synthesizer. The prf is controlled, as required, to avoid a blind speed condition for the target being tracked. The transmitter co-located with the antenna is a two-stage TWT coherent amplifier which delivers approximately 30 kW to the antenna. To provide discrimination against rain and clutter, particularly at extreme ranges, pulse compression is employed. An 11-bit Barker code is used to modulate the phase of the transmission in the up converter chain. Appropriate decoding on receive reduces the effective pulse width and concommitent clutter intake.

The Receiver is a double IF system with a TRL Limiter, pin diode attenuator, and RF amplification. The TRL Limiter, pin diode attenuator, RF amplifier, and the first IF amplifier are located at the antenna with the transmitter power amplifier stages. The signal at the 2nd intermediate frequency is transmitted by cable to the rest of the radar system housed in the instrumentation van.

The TRL Limiter and pin diode attenuator are packaged together to provide protection to the RF amplifier from transmitter leakage and AGC control to avoid system saturation. The RF amplifier consists of a GaAs FET amplifier. This "front end" provides for a receiver noise figure of 6.5 dB and an AGC control range of 60 dB.

The principal receiver output is in the form of quadrature channel (I and Q) phase detected outputs. Pulse compression is an operator select feature. An auxiliary receiver output supplies envelope detected video as a monitoring function.

Signal processing is performed by software in the array processor. Signal processing consists of time weighting, spectral analysis (FFT), and energy calculation of separate time sequences formed to the two lobes and two range gate combinations. These spectra are incoherently integrated to form the spectra corresponding to the two lobes, the early and late gates, and the total signal. A ***greatest of filter*** is performed upon the signal spectra to define the ***greatest of filter*** pair. This pair of frequencies is used to select the proper energy spectral pairs from each of the types of spectra to calculate the vernier ratio for the frequency, range, angle and amplitude measurement. The signal spectra is then passed through a low pass filter to provide an estimate of the spectral map for display purposes.

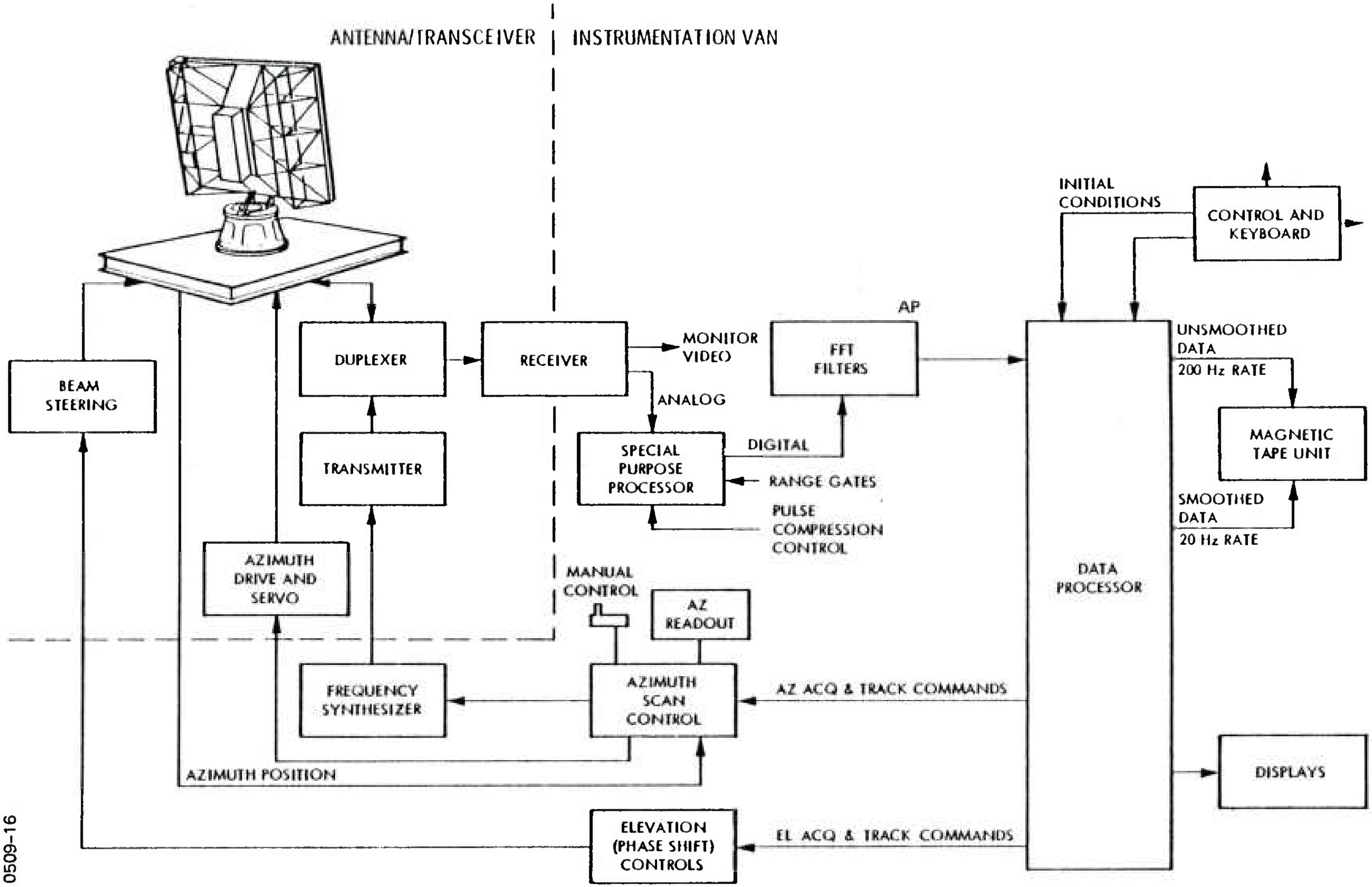

Figure 3-1. ARBAT overall functional system block diagram

Target acquisition and track initiation is facilitated by an acquisition computer function, operating on the vernier ratios to determine initial values of range, azimuth, Doppler, elevation and signal strength. After acquisition is accomplished, range and elevation tracking are rather straight forward functions. The former is a digitally controlled split-gate (early-late) tracker, while the latter controls the elevation position of sequential lobes by means of phase shifters. Azimuth and Doppler tracking are more complex, involving the simultaneous control of both the mechanical and electronic scan and filter output interpolation function. The electronic azimuth position scan is controlled by the updating of the target motion and mechanical scan positions while tracking information is obtained from a pair of azimuth sequential lobes generated by means of frequency scanning.

Since the mechanical azimuth tracking of the antenna will experience a lag during tracking, the data processor will provide not only the commands to the frequency synthesizer for electronic track, but also programmed commands to the azimuth mechanical servo subsystem to compensate for or anticipate the lag; and, since Doppler frequency is proportional to the frequency transmitted, the data processor takes this into account in converting to velocity. Further, the apparent Doppler frequency may have ambiguities involving integral values of the prf which is resolved by a knowledge of the prf being used and the approximate velocity of the target. The latter will be obtained either from track data or from a jittered PRT measurement during acquisition.

To summarize, the signal processor and data processor combine to:

a) Detect targets automatically using a CFAR detection algorithm.

b) Extract moving targets.

c) Avoid moving clutter with adaptive purge filters.

d) Enhance the signal detection capability by using amplitude weighting on both coherent and incoherent integration techniques in the signal processing.

e) Control the antenna during acquisition and when the target is acquired initiate tracking.

f) Control tracking patterns and develop tracking error signals.

g) Command the antenna phase shifters and the frequency synthesizer to keep the beam on target.

h) Interpolate between digital filter outputs to track the Doppler frequency of the target.

i) Calculate the radar cross section of the target from a knowledge of the system parameters and the target's range.

j) Perform coordinate transformations.

k) Store the estimated position and rates of the trajectory of the projectile so that the tracking circuits may be commanded to follow through in the event of losing the target due to noise or low angle condition.

l) Control a collocated magnetic tape recorder so that the entire trajectory record of the data is available for subsequent processing.

m) Provide signals and control to graphic displays.

3.2 ARBAT OPERATIONAL SEQUENCE

A complete operational procedure is presented to provide a framework for the system analysis and subsystem descriptions which follow.

3.2.1 Equipment Setup (Performed once when the system is initially set up.)

It is assumed that a radar site has been selected in advance of the date of test firing of ammunition and that survey of all weapon sites with respect to the radar has been completed.

The radar and prime power sources are set up at the designated site. Cabling is connected, the antenna vehicle leveled, and the antenna is aligned to surveyed markers.

3.2.2 Test Plan Setup

Designation of Weapon Sites

A firing test plan may involve up to five weapon sites. Shots from a given site should be repetitive (i.e., identical weapons, ammunition and firing angle). Firings may rotate among sites at a minimum interval of three minutes between firings.

3.2.3 Preliminary Data Entry Phase

All data to be entered into the computer for each firing test is entered using the Software Editor to modify the source program of the software subroutine SITEID using a separate identification ID for each firing site. The data input includes the following data:

- Location of the firing site.
- Location of the radar site.
- Weapon firing angles (i.e., Aspect, Bearing).
- Projectile characteristics (missile velocity, RCS, diameter, weight, ballistic coefficient).
- Special Track Options (antenna tilt, azimuth beam offset, pulse compression, purged filters).
- Trajectory intercept time.
- Special graphics and magnetic recording instructions.

Once in routine SITEID has been edited, it is compiled and loaded with the remaining portion of the track program to start the test.

3.2.4 Dry Run

For each test plan, a dry run will be performed. The initial search mode calculations will present data concerning the initial angular rates, Dopper velocity, maximum elevation angle, and search gate position. This data will indicate any problem which can be solved by specifying an azimuth beam offset, different intercept time (changing gate position), or a different antenna tilt. A dry run is then initiated to determine if any clutter problems exist. If problems exist, the antenna and range gate may be directed toward the point of the problem for further examination. Under static conditions, the outputs of each of the FFT filters may be examined. This data can be used for a decision to (a) abort the shot, (b) modify the firing conditions for the shot, or (c) modify the filter purging instructions. Any change to the input data will make it necessary to repeat the Preliminary Data Entry Phase.

3.2.5 Prepare for Test Start

Preliminary to the start of the actual test plan, the following items will be performed:

Antenna Tilt Adjustment

The antenna tilt will be manually adjusted in accordance with a test firing plan. It is not anticipated that the antenna tilt will be adjusted more frequently than once every several hours.

Radar Checkout

Transmitter power and receiver sensitivity will be measured. Operational tests are performed including tracking of the calibration reflector (with simulated Doppler offset) and exercising the radar through a computer test trajectory.

Data Recording Preparation

A magnetic tape will be set up for the test, a supply of terminal hard copy paper is checked, and the log books are updated.

3.2.6 Test Initialization

Before each test, the ARBAT track software is initiated. The program preliminaries are performed and the preliminary data base is set up. The proper test ID is entered into the program to select the proper test plan. Any last minute data corrections may be entered. The initial computations are performed and the results presented to the operator. Any additional changes can be made. When the operator is satisfied with the search mode, the initial commands are calculated and executed to move than the antenna into position and to give the program temperature information for the latest temperature correction. The system is then set into a mode to wait for the fire signal indicating moment of firing.

3.2.7 Initial Computations

The initial computations are based upon the data entry. The search gate position is selected by the calculated trajectory position of the target at the intercept time. The target position and motion is calculated in terms of radar parameters (range, azimuth, elevation) signal strength and then converted into radar commands (frequency, phase, servo position, AGC command, and range command).

3.2.8 Acquisition

Upon an acquisition enable signal, appropriate search patterns selected on the basis of expected projectile velocity will commence. At the completion of the acquisition sequence, accomplished within 25 milliseconds after first possible detection, the system will initiate track. Detection is based upon a CFAR algorithm using the estimate of the average signal strength of the residual FFT filters as the clutter reference. The threshold selected corresponds to a false alarm rate of approximately 0.0001 during acquisition and 0.001 during track. The acquisition sequence consists of the detection of an azimuth/elevation lobed on acquisition frame one and the immediate detection of an elevation/azimuth lobe on acquisition frame three.

3.2.9 Track

During TRACK, the antenna beam will be commanded left and right of the targets azimuth alternatively for 32 transmitter pulses. A small phase adjustment will be made simultaneously to correct for the small movement of the beam in elevation with respect to frequency.

The beam will then be commanded above and below the targets elevation alternately for a total of 32 pulses. Each sequence of 32 pulses is considered a frame of data.

The following sequences will provide tracking error signals for beam control and trajectory data for the record.

Sequence in Azimuth Control

Azimuth control functions will occur in the following sequence:

1) Measure the current azimuth position using the relative amplitude of the video in the two lobe positions. Estimate the current target azimuth position using the previous estimate and current measurement in an $\alpha-\beta$ filter. Obtain an estimate of the measurement residual.
2) Measure and estimate (using an $\alpha-\beta$ filter) the position and rate of the servo position during the center of the 32 pulses of data.
3) Using the current estimate of the target azimuth and servo movement, predict the target azimuth position for the next frame.

4) From the estimate of the azimuth residual, select the lobe separation for the next frame. Calculate the azimuth command (transmission frequency) for the next azimuth frame.
5) Calculate the servo command necessary to place the target in the azimuth midscan position (or the offset position - if used). To avoid an overshot, modify the servo command using a low pass filter (α filter) before issuing the command.

Sequence in Elevation Control

Elevation control will be performed in the following sequence:

1) Compute elevation measurement based upon relative amplitudes for the two lobe positions and upon the position of the last elevation lobe pair. Estimate the elevation position and rate using an α filter for slow targets and $\alpha - \beta$ filters for fast targets. Estimate the elevation measurement residuals.
2) Predict the target elevation for the next elevation frame using the current estimates of position and rates.
3) Select the elevation lobe separation for the next elevation frame using the estimate of the elevation residual.
4) Calculate the elevation commands (phase) using the target elevation and transmission frequency.

Sequence in Range Gate Control

The range gate control sequence is as follows:

1) On each lobe pair, obtain range error.
2) Compute and store target range measurement.
3) Estimate the current range position and rates using an α filter for slow rates and $\alpha - \beta$ filter for fast targets. Estimate the range measurement residual.
4) Select the next range gate size using the estimate of the range residual.
5) Calculate the range command based upon the range position prediction and range gate size selected.

Sequence in PRT/Doppler Velocity Control

1) Measure the ambiguous Doppler frequency using the relative amplitude of the energy output of the FFT filters of the signal spectra to determine a Greatest of FFT output pair (GOF) of filters and split the GOF pair of filters.
2) Convert this ambiguous Doppler frequency to the unambiguous Doppler velocity measurement using the estimated ambiguity factor, the frame PRT and transmission frequency. Special care is needed around zero Doppler velocity.
3) Estimate the Doppler frequency and rate using an α filter for slowly changing targets and $\alpha - \beta$ filter for rapidly changing targets.

4) Using the current estimate of the Doppler velocity rate, and transmission frequency estimate frequency ambiguity of the next frame.

5) Determine the PRT of the next frame necessary to maintain the ambiguous Doppler frequency midway between the edges of the MTI bandpass filter.

Sequence in the AGC/Signal Strength Control

1) Measure the signal strength using the GOF filter output (corrected for saddling losses due to the split FFT filters, split range gate positions, and sequential lobe position) and the AGC control which was applied.

2) Estimate the signal strength using an α filter and the current estimate.

3) Calculate the AGC attenuation (and then the AGC command) necessary to maintain the signal into the antenna at a specified level (-80 dBm) necessary to avoid saturation of the receiver. If an attenuation less than unity is needed (small signal level), remove all of the AGC attenuation.

4) Calculate the clutter level into the antenna using the GOF of the purged filters and the AGC attenuation and estimate using an α filter.

5) Calculate the residual level into the antenna using the average of the unpurged filters not containing the signal and estimate using an α filter.

6) Perform a CFAR detection by declaring a hit if the measured signal strength into the antenna is greater than a threshold based upon the estimated residual level.

Radar Control During a Miss Frame

1) Update only the signal clutter and residual levels and servo position estimates based upon their respective measurements.

2) Update the position and rate estimates of the elevation, azimuth, range, and Doppler velocity using only the previous estimates and rates.

3) Estimate the measurement residuals using a specified estimate of the measured residual.

4) Increment a miss counter. If the miss counter is greater than a specified amount, declare a lost track, and go to the reacquire mode; or Continue with the normal track variable predictions before the next frame and new command calculations.

Summary Processing Sequence

1) The average range, elevation, azimuth, servo, and signal strength variables over a fifty millisecond period are formed by dividing the sum of the variable types estimated during the period by the number of estimates.

2) Convert the averaged variables into the target position in gun coordinates by applying the scan equations to get antenna coordinates, rotating by the servo angle to get radar coordinates, and performing a translation and rotation by the bearing angle to obtain gun coordinates.

3) Estimate the trajectory position and rates using an $\alpha - \beta - \gamma$ filter for the height and down range coordinates and $\alpha - \beta$ filter on the cross range coordinate.

4) Estimate the total velocity by finding the square root of the sum of the square of the three velocity components.

5) Output the downrange, height, and velocity data to the real time display.

Auxiliary Operations

1) Store the data to be recorded into their appropriate subbuffers. Output the total buffer when filled.

2) Prepare the radar commands for output and send to the SPP.

Reacquire Sequence

1) When the miss counter in the tracking mode has reached its maximum value, switch the mode to reacquire.

2) Continue the trajectory position estimates using the previous estimates of position and rates.

3) Set the measurement residual estimates to their specified maximum values to increase the lobe separation and range gate size to a maximum. Using the last PRT, calculate a second PRT to avoid blind speed and set the search pattern in operation.

Section 4

OPERATOR PROCEDURES

Section 4

OPERATOR PROCEDURES

4.1 REAL-TIME SOFTWARE OPERATION

ARBAT Real-Time Software is controlled through the Tektronix Keyboard/CRT terminal in the operations van. The operator may call up the real-time program by typing in 'H' and 'cr' (carriage return). The operator will then be led through a series of menus and prompts to select between various options and to enter or change various tracking parameters (i.e., firing site, Q.E., initial velocity, bearing, etc.). The actual commanding of the radar and data-taking may be initiated by either the operator at the keyboard or the gunfire interrupt signal. The run may be terminated by either the operator or by certain automatic termination criteria in the software which the operator may set.

4.1.1 System Boot

At the Eclipse front panel, lift data keys 0,11,12,14, and 15 to the up position with the remaining data keys in the down position. Lift the Program Load Key momentarily to the up position. The Tektronix should display "Filename?" in the upper left corner of the screen. At the Tektronix terminal enter 'cr' (the carriage return key). The screen should display a prompt for the date. Enter the month (one or two digits), a space, the day (one or two digits), a space, the year (two digits), and 'cr'. The screen should return with a prompt for the time. Enter the hour (0-23), minute (0-59), second (optional; 0-59), and 'cr'. The screen should return with '=>' which indicates that the system is ready for an operator input. Enter 'A' and 'cr' to initialize all of the necessary files and wait for the screen to display another '=>'. Enter 'KLEAR' and 'cr'. When ∧ screen fills, push 'clear' key in the upper left corner of the keyboard. Wait for '=>' again.

4.1.2 Site Data Initialization

Currently the various parameters for a firing or for taking data on a radar reflector are initialized in a Fortran program. This program allows the operator to select between seven different sets of parameters. Each parameter may then be modified individually if desired, as described in Section 4.1.6. In order to make any permanent changes to these parameters, the program SITEINIT must be edited and compiled, and the entire real-time program must be reloaded.

4.1.3 Initiating the Program

All of the real-time programs reside in directory DROP:MAIN which is where the system should be if the instructions in 4.1.1 were followed. To initiate the real-time program, type in 'H' and 'cr'. This will cause the system to execute a command line which initializes the various devices and brings in the initialization overlay of the real-time program. Wait for the I/O menu to appear on the CRT (within a few seconds) and proceed to 4.1.4.

4.1.4 I/O Menu

The I/O menu allows the operator to change various I/O related options. The defaults are set for a normal firing. However, option 2 controlling the status of MTO should be verified before proceeding. If the tape contains files which are to be saved, the status must be set to 'OLD'. To proceed, type 'O' and 'cr'. If a tape drive is enabled, the operator will be prompted for a run number. This number is placed in the data base which is written to tape and is for reference only.

4.1.5 Test Select Menu

For a normal firing, test 10 should be used. Test 9 may be used for special testing. If test 9 is selected, the video area of the data written to tape will be overlayed with tracking data (see 4.2.2).

4.1.6 Test Parameters Menu

Normally, the SITEINIT Program should be edited before a set of firings to prepare the desired set(s) of default parameters (4.1.2). However, if during the firings any of the firing parameters (rcs, QE, bearing, muzzle velocity) are changed or a different intercept time (angle) is desired, the operator may change any or all of these through the main test parameters menu. Selecting a different firing site ID (option 4) will automatically set all of the above parameters and the ballistic integration data (option 11) to whatever is set in the SITEINIT Program. Option 10 (Change Data Base Defaults) may be used to change many of the other data base variables. The most commonly changed variables are in the RADAR DATA BASE group of the sub-menu and include reference constants, site coordinates, and termination criteria.

To proceed from the main Test Parameters Menu, enter 'O' and 'cr'. The screen will then display the radar search position and conditions calculated from the input parameters. The operator may then return to the main Test Parameters menu to modify one or more parameters, or may proceed by typing in 'O' or 'cr'.

4.1.7 Command Menu

For a normal firing, the Command Menu is used only to verify that the proper commands have been calculated. To proceed, enter 'O' and 'cr'.

4.1.8 Initiating the Run

When the CRT has finished drawing the graphics grids and displays the message 'ENTER ∧ D9', the program is ready to initiate the Search mode and to begin taking data on mag tape. Press the 'cntr' and 'D' keys simultaneously; then press key '9'. The mag tape should begin recording data. If and when the system detects a signal and initiates a track on it, the screen will start displaying the elevation versus range and the velocity versus range graphic.

4.1.9 Terminating the Run

A run will normally be terminated in one of the following ways:

a) The operator types in 'cntr' and 'D' simultaneously and then key '5'.

b) During or after a track, the tracker gets a predetermined number of misses (set by operator).

c) During a track, the tracker residue level goes above a predetermined level (set by operator).

When the run is terminated, the elapsed time counter on the screen will stop counting. The operator may then press the 'copy' key to make a hard-copy of the screen. Enter 'cr' to write a double EOF on the mag tape and return to the main I/O menu. Press 'cntr' and 'A' simultaneously to exit the program.

4.2 OPERATION OF OFF-LINE PROGRAMS

Anytime after a firing, the operator may analyze the data taken during the firing by using various data reduction and analysis programs resident on disk. The Summary Processing Program is used for both impact prediction and creating a summary tape.

There are two graphic programs, one for graphing variables from the detailed tape on the Tektronix terminal, and a similar one for the summary tape. There are also programs for selective dumping of data from the tapes onto the highspeed printer.

4.2.1 Summary Processing

The Summary Processing program is used to create summary tapes from detailed tapes, and to do impact point prediction. The write-ring should be removed from the detailed tapes, and the tape may be mounted on either drive. If a summary tape is to be created, a scratch tape with a write-ring inserted should be mounted on the other drive. Type in 'SUMMARY' to call up the Summary Processing Program. The screen will prompt the operator for drive and file information, and then display the Impact Prediction Menu. Option 1 is for enabling or disabling impact prediction. If it is disabled, the other options are meaningless. Option 2 allows the operator to determine the point at which the integration should start. Setting this option to 'AUTOMATIC' will make the program start the integration when the residual level goes above the specified level. Setting the option to 'TIME' will make the program start the integration at the specified time. Option 3 determines the height at which the integration is to be terminated. This is defaulted to the gun position height from the data base. Options 4,5, and 6 are for setting constants used for the integration and are defaulted to values from the data base. To proceed from the Impact Prediction Menu, enter 'O' and 'cr'. When the impact prediction results are displayed on the screen, the operator may make a hard-copy of the results by pressing the 'copy' key on the keyboard. At the completion of the conversion the screen will display the prompt 'IF YOU WANT TO DO ANOTHER TAPE ENTER 1'. If there are no more files to convert, the operator must enter 'O' and 'cr' in order to write the tape mark onto the tape.

4.2.2 CRT Graphics Programs

The graphics program for the detailed tape is called up by typing in 'GR' and 'cr'. The operator will be prompted to enter the file number. The files are numbered from zero. Next, the operator will be prompted for the beginning record number. Although the records are numbered from zero, the first record is the data base and should not be graphed. The next prompt is for the number of files, and this should normally be answered 'O' (all records). The next prompt, for bandwidth, is applicable only for the special filtering function. For normal graphs it should be answered 'O' and 'cr'. The next several prompts refer to the actual graphing itself. Refer to Table 4-I for the variables which are available for graphing. The final prompt asks for the mag tape number, and should be answered either 'O' or '1' and 'cr'.

Table 4-I. Placement of Data on Detailed Tape

GROUP 1: HEADER WORDS
TYPE: INTEGERS

0) BUFFER NUMBER
1) SURBUFFER NUMBER
2) DOPPLER FREQ AMBIGUITY
3) RANGE AMBIGUITY
4) MISS COUNT
5) TRACKER MODE
6) PATTERN
7) AZ BEAM RESIDUAL (*10)
8) EL BEAM RESIDUAL (*10)
9) RANGE RESIDUAL (*10)
10) CLUTTER/NOISE RATIO
11) SIGNAL/NOISE RATIO

GROUP 2: COMMAND WORDS
TYPE:

12) TRACK DISCRETES
13) EL COMMAND 1
14) EL COMMAND 2
15) AZ COMMAND 1
16) AZ COMMAND 2
17) SERVO COMMAND
18) PULSE GROUP DEFINITION
19) PRT COMMAND
20) AGC COMMAND
21) RANGE COMMAND

GROUP 3: SPP INPUTS
TYPE: INTEGERS

30) SERVO POSITION
31) TEMPERATURE
32) ELAPSED TIME
33) TOD1 (NOT IMPLEMENTED)
34) TOD2 (NOT IMPLEMENTED)
35) SY D
36) BITE 1
37) BITE 2

GROUP 4: VIDEO (OVERLAYED WITH TRACK DATA)
TYPE: REAL

38) MEASURED AZ BEAM NO.
39) MEASURED EL BEAM NO.
42) MEASURED RANGE
44) MEASURED DOPPLER VEL
46) MEASURED SERVO POSITION
48) MEASURED SIGNAL LEVEL
50) MEASURED NOISE LEVEL
52) MEASURED CLUTTER LEVEL
54) SEPARATED LOBING VERNIER
56) AZ BEAM VEL
58) EL BEAM VEL
60) RANGE VEL
62) MEASURED SIGNAL LEVEL BEFORE WEIGHTS APPLIED
64) SERVO VEL
72) AZ BEAM COMMAND CENTER
74) EL BEAM COMMAND CENTER
76) PREDICTED RANGE POSITION
78) PREDICTED DOPPLER VEL
80) PREDICTED SERVO POS
82) GAIN
84) RANGE RESIDUE ALPHA
86) FILTER 0
88) FILTER 1
90) FILTER 2
92) FILTER 3
94) FILTER 4
96) FILTER 5
98) FILTER 6
100) FILTER 7
102) FILTER 8
104) FILTER 9
106) FILTER 10
108) FILTER 11
110) FILTER 12
112) FILTER 13
114) FILTER 14
116) FILTER 15
118) GOF
120) LOWER INDEX OF GOF PAIR
122) HIGHER INDEX OF GOF PAIR
124) DOPPLER VERNIER
126) RANGE VERNIER
128) LOBING VERNIER
130) CALCULATED TARGET AZIMUTH
132) CALCULATED TARGET EL ANGLE
134) DEBUG WORD 1
136) DEBUG WORD
138) DEBUG WORD
140) DEBUG WORD

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Table 4-1. Placement of Data on Detailed Tape (Continued)

GROUP 5:	RADAR STATE VECTOR
TYPE:	REAL
167)	FRAME TIME
169)	SMOOTHED SERVO POS
171)	SMOOTHED AZ BEAM NUMBER
173)	SMOOTHED EL BEAM NUMBER
175)	SMOOTHED RANGE
177)	SMOOTHED DOPPLER VELOCITY
179)	SMOOTHED SIGNAL LEVEL

GROUP 6:	SPARE WORDS
TYPE:	REAL
181)	SMOOTHED CLUTTER LEVEL
183)	SMOOTHED RESIDUE (NOISE) LEVEL
185)	MEASURED DOPPLER FREQUENCY
187)	SERVO ERROR
189)	SERVO FEEDBACK GAIN
191)	TRACK QUALITY

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There is a separate program for graphing variables from the summary tape. This program is called up by typing in 'SGR' and 'cr'. The procedure for using it is similar to the procedure for the one for detailed tapes; however, instead of referring to Table 4-I, the operator will be provided a menu on the screen of all the variables which are available for graphing.

4.2.3 Printer Dump Program

The printer dump program is used for dumping data from either the detailed tape or the summary tape onto the high-speed printer. The program is called up by entering 'DUMPTP' and 'cr'. This program uses the same method for numbering records and files as the graphics programs (4.2.2).

Section 5

PERFORMANCE TEST RESULTS

Section 5

PERFORMANCE TEST RESULTS

Between September 27, 1979 and October 4, 1979, the performance capability of the ARBAT Radar System was demonstrated to representatives of the U.S. Army Armanent Research & Development Command (ARRADCOM) and Yuma Proving Ground (YPG). This test was designed to demonstrate the ARBAT Radar System capabilities of tracking a 155 mm projectile over a wide range of test conditions. The validity of the resulting track data was verified using the GE203A Muzzle Velocity Radar and impact observers during various test rounds.

The Performance Demonstration test results indicated that the greater part of the ARBAT project goals were met and that the problems encountered and demonstrated during the tests could be overcome in the upcoming follow-on work.

During the tests a total of 134 projectiles were fired, 79% (106) were tracked, and 50% (67) were tracked to impact. Test analyses indicate that, with minor problems corrected, the operational ARBAT Radar System should be able to track 96% of the fired projectiles with a 90% track to impact capability. The next several sections will describe the parameters tests, results, and analysis of the Performance Demonstration Test.

5.1 MEASUREMENT PARAMETERS

The instrumentation mission requirements for which the ARBAT system was designed include an extensive list of widely variable test targets and test conditions. These variables include a range of target types and ballistic factors as well as a wide range of firing site and trajectory angular relationships with respect to the ARBAT system location. Range priorities and range safety constraints limited the test/demonstration activities covered by this report to test firings from fire site 18. (See Figure 5-1.) The ARBAT system is transportable over unpaved road surfaces, however, site preparation is required for optimum accuracy, in addition to requirements for prime power (base power). As a consequence, all testing covered by this report was from a single radar site near the northern end of the KOFA Firing Range West where the antenna subsystem is mounted on a poured reinforced concrete pad for maximum rigidity and positioning repeatability.

The measurement parameters covered in this report includes only the munitions, conditions and test situations as approved for the system test/demonstrations in the test period between Sept 1979 and the completion of the tests in October 1979. Other tests conducted as a part of the development program phase at YPG included both mortar and 105mm munitions and are not included in this report.

The general test parameters and test data are as follows:

Munitions -	All tests were conducted with the 155 mm round.
Test Firing Site/ Radar Location -	See Figure 5-1 for locations of the ARBAT system with relationship to Fire Site 18.

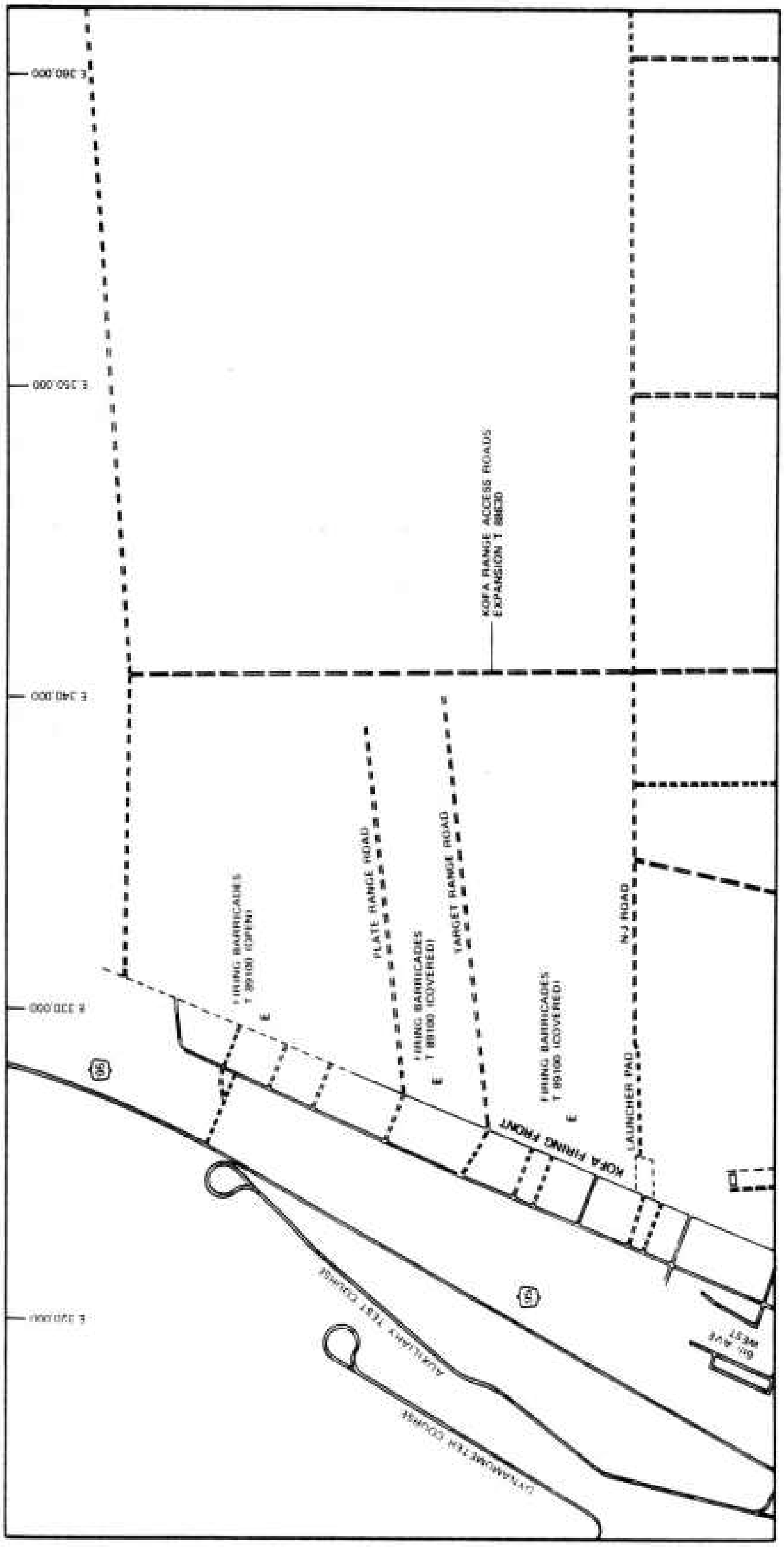

Figure 5-1. Yuma proving ground firing site

Weapon elevation	- QE's of 300 to 1200 inclusive.
Weapon line of fire	- Various from FS-18
Impact area observers	- Yes:
ARBAT System Test Data	- Target intercept time (in milliseconds) Target intercept angle Target velocity from intercept to impact on loss of track at last data point before impact. Positional data throughout trajectory Target signal levels throughout trajectory Impact position prediction

5.2 TEST OBJECTIVES

The primary objective of the Performance Demonstration Tests was to test the capability of the ARBAT Radar System to:

1) intercept the target,
2) track the target,
3) record accurately the target trajectory parameters
4) predict the target impact point over a wide range of initial target parameters.

Secondary capabilities which were to be demonstrated if time permited, included:

1) intercept time (minimum elevation angle) variations
2) event detection such as ICM's and RAP's, and
3) operation in diverse weather conditions as encountered.

To satisfy these objectives a test plan was developed with the assistance of ARRADCOM and YPG personnel. The test plan was generated with the following objectives in mind.

1) Satisfy the test objectives (as mentioned above).
2) Fire all shots of a particular day into one range area (to keep the impact observers from having to move).
3) Demonstrate a particular capability each day.
4) Initiate the demonstration with tests assumed to be easiest to perform and increase the difficulty each day (so that any radar characteristics observed early in the test may be used later).

Unfortunately, the test plan was not followed due to the following reasons:

1) only four days of testing were allowed instead of the originally planned five days due to range priority considerations at YPG.
2) the need for the GE velocity measuring radar for other programs necessitated the change of test No. 1 (velocity measurement) until the midtest point.

The Performance Test Plan that was actually implemented is shown in Table 5-I. The muzzle velocity test originally scheduled first was rescheduled for the second and then the third day due to the unavailability of the GE velocimeter radar. Hardware problems caused the first day of testing to be delayed until the end of the day resulting in only ten of the originally planned 30 shots to be fired. It was jointly decided to reschedule the first complete day of testing to the second day of firings.

Table 5-I. Implemented ARBAT Testing

Test Date	Originally Scheduled	Rounds	QE	Bearing	Charge	Muzzle Velocity	Test
Sept 26	2	1-10	800	112	5	375	Acquisition Time high QE/ON range (10km)
Sept 27	2 (repeat)	1-10	800	112	5	375	Acquisition Time
		11-20	1200	112	6	476	high QE
		21-24	1200	108	7	566	low range (10km)
Sept 28	3	1-10	800	106	6	776	Low QE
		11-13	440	106	7	566	medium range
		14-20	440	102	7	566	(12km)
		21-30	300	102	8	686	
Oct 1	1	1-10	600	106	4	319	muzzle velocity
		11-20	400	106	5	375	low QE
		21-30	300	106	6	476	low range (8km)
Oct 2	4	1-7	520	103	8	686	High range (16km)
		8-15	520	100	8	686	
		16-3	100	100	8	686	
Oct 4	2 (repeat)	1-10	1200	100	7	566	Low range (10km) high QE

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Additional delays during the second day caused only four of the called for ten rounds to be fired. The final set of rounds (last ten of day 1) were rescheduled until the end of the test schedule. The remaining shots were all fired according to the modified schedule.

5.3 TEST RESULTS

The results of the ARBAT Performance Demonstration Test is shown in Table 5-II. Table 5-II presents the same test results tabulated according to the length of time between the actual firing and when the ARBAT system declared track termination. The length of the track helps in determining whether the estimated trajectory actually impacted the ground plan and if not could possibly point to the cause of the loss of track. Table 5-III defines the categories of the "time in track" and lists the possible causes of loss of track for each category. Tabulated next to the possible causes of track are the letters R, D, P or F which indicate whether the trajectory termination was due to a dumb error (D), a possible problem which needs to be corrected (P), or a problem which is corrected by correcting the amount of residue. This indication of the track termination is used in the next section describing the analysis of the test results.

Table 5-II. ARBAT Performance Demonstration Test Results

Date	QE	Bearing	(Range/ Muzzle) Velocity	Rnds	GT	DET	AQ	LHT	GHT	FT
Sept 26	800	112	5/375	10	8	5				3
27	800	112	5/375	10	10				1	9
	1100	112	6/476	10	9				4	5
	1200	108	7/566	4	4			4		
28	800	106	6/476	10	10		1	1	1	7
	440	106	7/566	3	3				2	1
	440	102	7/566	7	7		2			5
	300	102	8/686	10	10		3			7
Oct 1	600	106	4/319	10	10					10
	400	106	5/375	10	10					10
	300	106	5/476	10	10		1			9
Oct 2	520	103	8/684	7	7	1	2	1	3	-
	520	100	8/684	8	8	1		1	6	-
	1040	100	8/684	15	14		4	3	7	-
Oct 4	1200	100	7/566	10	10		3	1	6	-
			Totals	134	130	7	16	11	30	66

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Table 5-III. Performance Test Categories

RNDS – The number of shots fired in the given test configuration.

Det – The number of shots which were not tracked but whose amplitude signature was sufficient for detection. Test shots fell in this category due to:

- D0. Pointing errors due to incorrect input of test parameters
- D1. target passed through edge of search gate – beam bias set wrong
- D2. lobe separation was too large causing signal energy loss in the center of the lobing
- D3. target angular velocity exceeded the limit for the launch site/radar geometry azimuth offset entered
- P4. tracked on clutter before target appeared
- P5. hardware error

AQ – The number of shofts acquired but lost track within one second of acquisition. Shots belonging to this category include:

- D1. targets whose azimuth rate was so large it out ran the servo system – fixed by additional separation of the servo position/azimuth beam offsets.
- P2. targets whose acquisition measurements were in error
- P3. false targets because of detection of clutter

PT – The number of shots whose track was established but were lost before the target reached impact. Reasons for loss of targets in this category include:

- D1. elevation exceeded design limits (incorrect antenna tilt)
- D2. signal was lost because of additional clutter from cross polarization lobes
- P3. amplitude tracking filter was too slow for a sharp scintillation
- S4. residue from clutter or noise was too large for the loss of target signal amplitude resulting from scintillation or excessive range
- P5. hardware error
- P4. the track was started with the wrong frequency ambiguity

LHT – A partial track which terminated before maximum ordinate was reached.

GHT – A partial track which terminated after maximum ordinate was reached.

GT – good test record

FT – The number of shots which were completely tracked to impact.

D – a dumb error: Loss of track acquisition or earlier track loss due to an error caused by incorrect data input due to operator inexperience. The problem could be corrected with more experience in operating the system.

P – a problem error: Loss of track acquisition or earlier track loss due to a problem which will take additional studies to solve. Examples of this type error include hardware errors (except for the resident problem), catching the wrong frequency ambiguity, etc.

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Table 5-III. Performance Test Categories (Continued)

R	– residual error:	One particular error which was noted during the test which appeared only 2 - 3 weeks previously. The signal-to-residual ratio appears to be reduced by about 10-12 dB compared to previous results. This caused loss of track during a scintillation or at a shorter range than expected due to loss of signal into the residue (noise and/or clutter residual).
F	– full track: a track to impact.	

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5.4 TEST ANALYSIS

Section 5.2 concerning Test Objectives indicates that the primary test objectives of the ARBAT Performance Demonstration Tests was to test the capability of the ARBAT Radar System to:

1. intercept the target
2. track the target
3. accurately record the trajectory parameters, and
4. predict the target impact point.

This Test Analysis Section will analyze the test results with regard to these primary objectives. The analysis will use individual tracks to determine cause of an imperfect track, and form an interpretation of that data as applied to an operational ARBAT Radar System.

The ARBAT Performance Demonstration Test was performed using a version of the on-line "Track" program which did not record the raw video data but did record many subcalculations and trajectory parameters not normally recorded. These variables ina ddition to the variables calculated in the summary program provide the capability to analyze a particular trajectory in great detail.

5.4.1 Target Acquisition

During the Demonstration Test a track was established on 106 of the 134 rounds that were fired giving an acquisition rate near 79 percent for these tests.

Table 5-IV presents a tabulation of the statistics of the causes of nonacquisition of these tracks. A detailed description of the causes is presented in Table 5-III. An examination of the causes of the missing tracks indicates that some percentage of the missed tracks were due to dumb errors which would be avoided in an operational system when the ARBAT staff has greater experience with the system. If the statistics due to the dumb errors were removed, then the system would have acquired some 106 firings out of 111 for a probability of acquisition of 96 percent. This statistic assumes that the target to be tracked passes a set of limiting criteria and the system performance is not affected by geometry.

5.4.2 Target Tracking

During the Performance Demonstration Tests 66 of the firings were tracked to impact out of the 106 targets fired resulting in a conditional probability of 0.623. The causes of the losses of an established track are tabulated in Tables 5-V, 5-VI, 5-VII and 5-VIII.

Table 5-IV. Reasons for Failure to Acquire a Track

Designation	Type	Number	Cause
A1	D	5	Beam Lobe Separation Too Large During Search Mode
A2	D	11	Elevation Bias was input wrong for a given antenna tilt
A3	D	2	Operator Input Error
A4	D	5	Az Beam Offset was input wrong for given servo requirements
A5	P	2	False Alarm Track on Clutter before the appearance of the target
A6	P	1	Bad Doppler Veolcity Measurement
A7	P	2	Hardware Error: SPP sent a bad buffer of data
	D	23	
	P	5	
		28	

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Table 5-V. Probability of Acquisition Tabulation

Statistics	Test Results Number	Test Results Probability	Dumb Statistics Removed Number	Dumb Statistics Removed Probability
Target Acquired	106	.79	106	.96
Miss due to Dumb Error	23	.17		
Miss due to Problem	5	.04	5	.04
	134		111	

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Table 5-VI. Reasons for Failure to Maintain an Established Track

Designation	Type	Number	Cause
C1	P	3	Hardware failure; SPP, magnetic tape unit, and transmitter
C2	R	17	Residual too large – caused loss of s/n
C4	D	4	MTI filler improperly selected by operator at high elevation
C5	D	14	Antenna tilt set wrong – tile too low/cross-polarization lobe problems
C6	P	1	Bad Doppler velocity measurement
	D	18	
	R	17	
	P	4	
		39	

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Table 5-VII. Probability of Full Track Conditional on an Established Track

Statistics	Test Result Number	Test Result Prob.	Dumb Statistics Removed Number	Dumb Statistics Removed Prob.	Dumb and Residue Statistics Removed Number	Dumb and Residue Statistics Removed Prob.
Impact	66	.62	66	.75	66	.93
Loss due to Dumb Error	18	.17				
Loss due to Residue	17	.16	17	.19		
Loss due to Problem	5	.05	5	.06	5	.07
	106		88		71	

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Table 5-VIII. Non Conditional Probability of an Impact Track

Test	(0.79) (0.62) = 0.49
Dumb Statistics removed	(0.96) (0.75) = 0.72
Residue Statistics removed	(0.96) (0.93) = 0.89

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Section 6

OPERABILITY

Section 6

OPERABILITY

The following paragraphs focus attention on characteristics of ARBAT relating to operating personnel in the areas of Human Factors, Safety and the Environment in which ARBAT has performed successfully to date.

6.1 HUMAN ENGINEERING

Both major groups of ARBAT equipment: the Instrumentation Van, and the Antenna Subsystem, have been the object of Human Engineering (HE) activities for enhancement of the Man-Machine interface. Activities in the HE area throughout the program, of general as well as specific nature, have been reported regularly as a part of the Quarterly Letter Progress Reports through LPR No. 11. To assess the adequacy of certain design features relative to HE (for example, noise, illumination levels and vibration), the Government measured certain features of the operator environment. A synopsis of these results are included in the review of the major equipment HE features provided below.

6.1.1 Instrumentation Van (IV)

HE activities in and around the IV were directed toward two goals: Compactness and convenience. The purpose of these goals were to keep the IV as small as possible for ease of mobility and to provide personnel comfort and operational and maintenance efficiency. Key equipment or equipment arrangement features relating to the HE goals are:

a) Clustering equipment about the operators position to provide ease of viewing equipment status.

b) Wide aisles to allow sufficient space for equipment maintenance but not block access throughout the IV.

c) VIP display and viewing area provided at the opposite end of the IV separated by a curtain to reduce interference or distraction due to visitor activities and conversations.

d) Well dispersed IV lighting, separately controllable within the operator and VIP areas. Variable adjustment of illumination provided for the VIP viewing area allows ambient light to be set for optimum VIP display viewing.

e) Air conditioning provides shirt sleeve comfort for both the operator and VIP reviewing areas.

f) Particular care was taken during development of display formats. All displays, especially the graphical presentations, were structured for clarity and comprehensibility.

6.1.2 Antenna/Trailer Subsystem

Ease of maintenance was the key element addressed by HE activities for this unit. The principal maintenance problems in this regard were simply hardware access and maintenance personnel exposure. The complete Transceiver as well as the Antenna phase shifters are well above ground level. While a convenient working surface did not exist near the Transceiver prior to April 78, the problem has been solved by the fabrication of a removable platform. In addition, since the Antenna/trailer is not radome enclosed for the ARBAT application, and any necessary maintenance requires the work be accomplished in current weather conditions Experience at Yuma Proving Grounds during the months of development testing clearly demonstrated the need of sun exposure protection for maintenance personnel, especially at the Transceiver location.

Following are the actions taken in resolving the HE problems in the Antenna/trailer.

a) A removable work platform with a two-man capacity supported by part of the Antenna back structure was located at the Transceiver.

b) A free-standing ladder of sufficient height to reach the upper most antenna phase shifters (with antenna at 20° tilt back) has been provided as a part of the ARBAT site equipment compliment. The ladder is additionally used to gain access to the Transceiver work platform.

c) Sun exposure protection for maintenance personnel was afforded by a simple but removable umbrella installation nearly identical to that used for similar protection of heavy equipment operators.

6.2 SAFETY

Specific safety features exist within each of the major groups of ARBAT equipment. As with other Human Engineering Factors these have generally been reported regularly as a part of the Quarterly LPR. Similarily the Government measured RF radiation levels to determine personnel safety aspects regarding equipment use. A summary of the key safety features as well as results of the Government radiation level tests is presented below.

6.2.1 Instrumentation Van

Emergency Exit

The van is designed with two large personnel doors located on opposite walls at opposite ends of the van. One door is intended for normal access and the other door (near the operator's console) is primarily an emergency exit.

Hand Rails

Steps with hand rails are provided at each door. These steps are attached to the van with raised perforated metal treads to eliminate the possibility of slipping in bad weather conditions.

Fire Extinguishers

A fire extinguisher is located on each door of the van.

Control of Radiation

The Radar Operations and Maintenance Panel (ROMP) located at the operator's station within the van has a Radiate Key Switch and a Radiate Inhibit Light (red lamp). This light is on (red) when the transmitter is not radiating, and out when radiating, causing the Radiation Warning Light (at the antenna) to go on. Radiation can be inhibited at the operator's station (ROMP) by turning the Radiation Key Switch "off" or placing the transmitter in Standby. For personnel to insure the transmitter will not be radiating when at the antenna, the Radiate Key Switch should be turned off and the key retained by these personnel.

Antenna Rotation Control

A Servo Disable Key Switch is located on the ROMP. Turning this key to "OFF" disables the Servo rendering the antenna pedestal inoperable.

6.2.2 Antenna/Trailer Subsystem

Antenna Rotation Control

A duplicate Servo Disable Key Switch is located in the Servo Control Box on the antenna trailer. The box is located beyond the Antenna swing radius and thereby is safely accessible to deactivate the Servo should the Key Switch in the Van be in the "ON" position when maintenance personnel require access to the Antenna.

High Voltage Interlocks

The transmitter will not radiate until the high voltage is "up". (A status light in the ROMP indicates when this condition occurs.)

At the Transceiver (Antenna), the high voltage panel within the unit is properly marked and is interlocked. When this panel is open, high voltage is off and cannot be turned on from the van ROMP.

The high voltage is interlocked to various functions within the Transceiver and Antenna as defined below:

- Excessive temperature through the Traveling Wave Tube (TWT).
- No air flow through the TWT.
- Failure of 28V power supply. This provides power for all interlocks.
- Antenna Phase Shifter Bias. This protects the phase shifters (radiation through the phase shifter without bias will damage the phase shifter.)
- The 28V power supply is also interlocked to the air flow through the Transceiver Case.

Maintenance Platform and Stepping Area

The platform provided for Access to the Transceiver is provided with guard rails. Additionally, areas on the trailer and pedestal that provide access to the equipment for maintenance are provided with non-slip strips or pads.

6.2.3 Radiation Tests and Recommendations

ARBAT system radiation measurements were conducted by both ITT Gilfillan and the Government. Following are summaries and highlights from these tests, as well as the recommendations made by the Government for proper disposition of findings.

6.2.3.1 ITT Gilfillan conducted Radiation Tests – Broadband radiation measurements were made by ITT Gilfillan Engineering to assess any potential safety hazard. Figures 6-1, 6-2, and Table 6-I present the measurement geometry and resulting radiation levels. As will be noted, all radiation levels measured were well below the 10 mW/cm^2 density, the presently accepted level for system safety. The Narda Model 8305 Broadband Isotropic Radiation Monitor was used for the measurements.

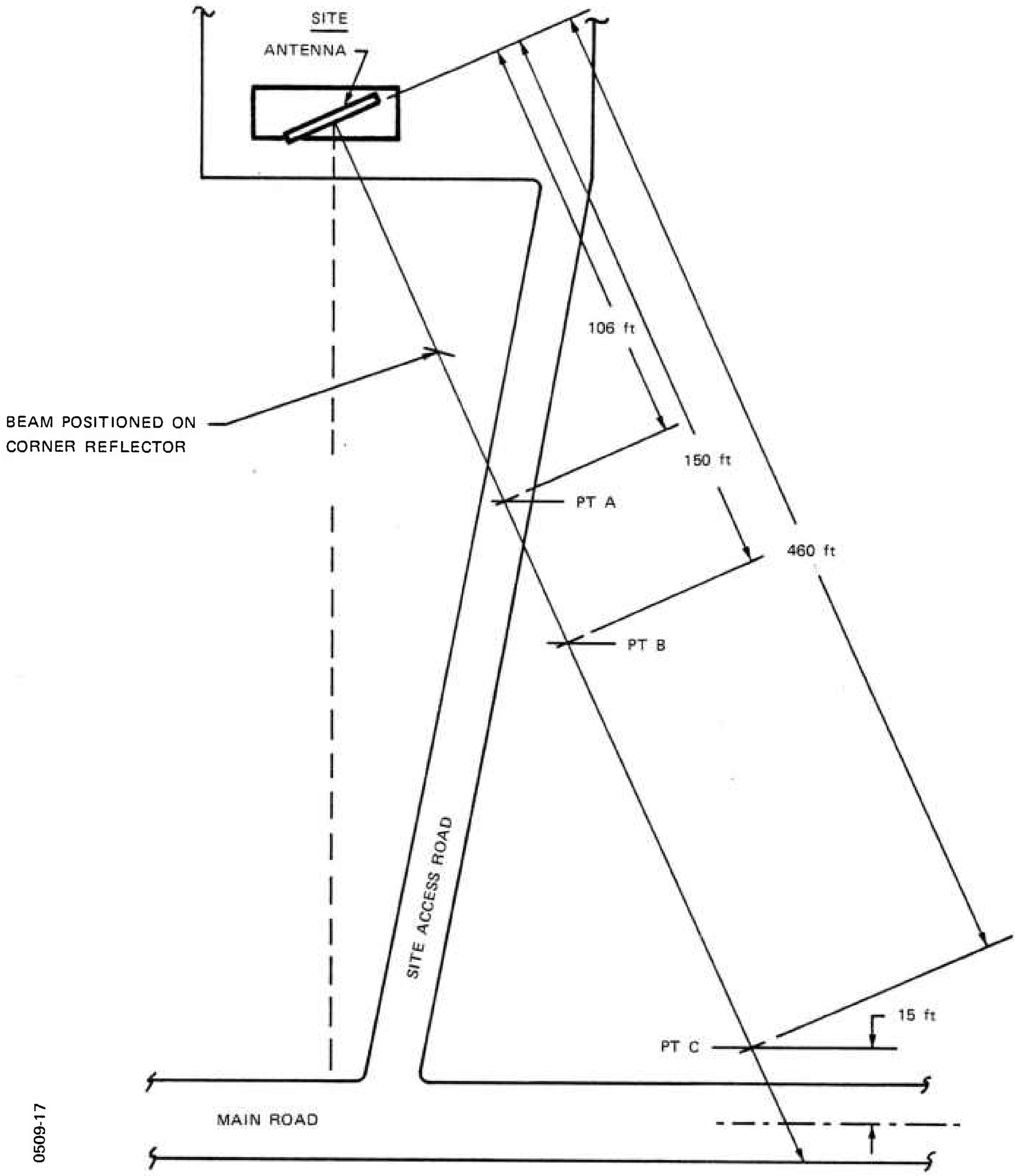

Figure 6-1. ARBAT radiation test geometry

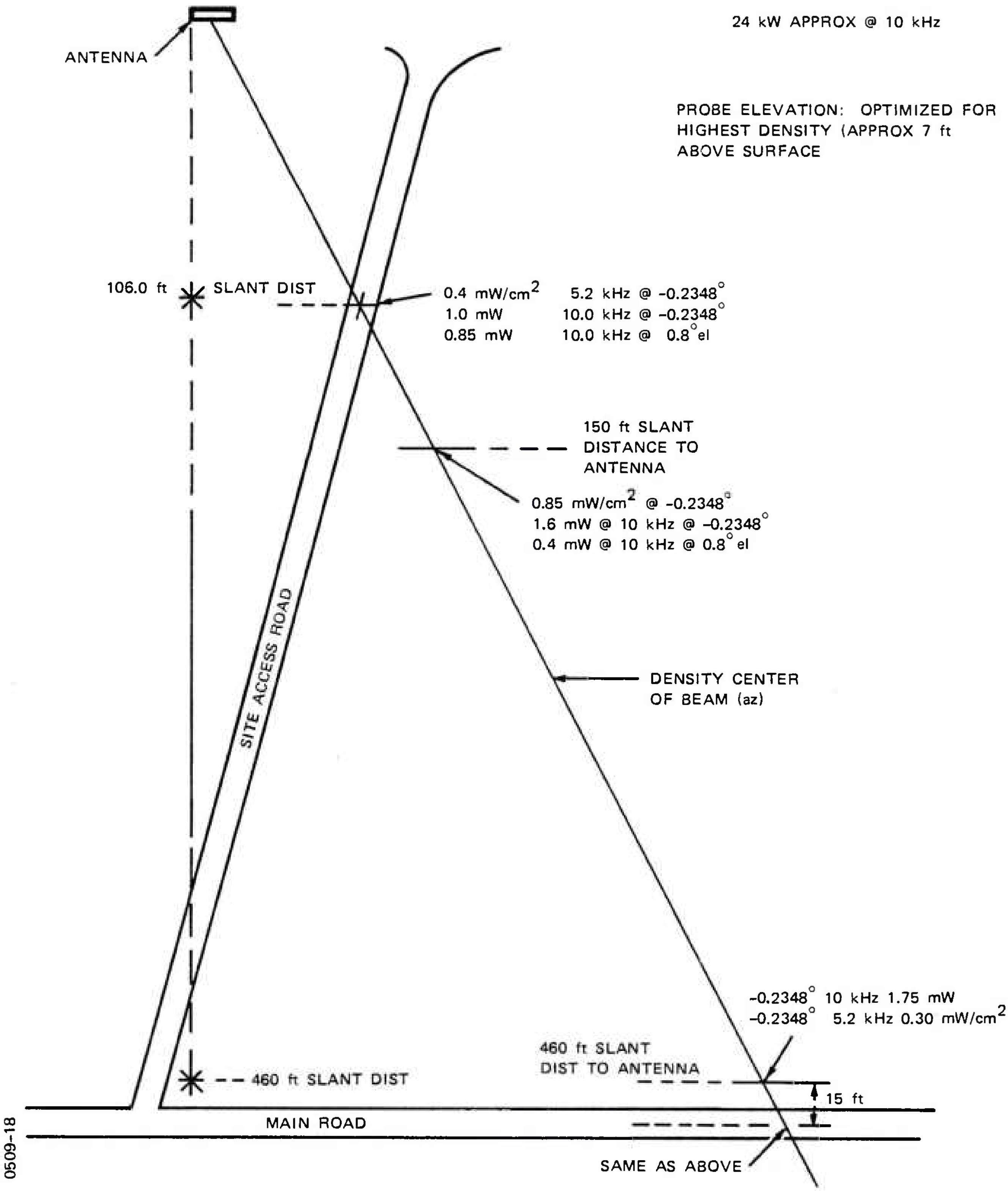

Figure 6-2. ARBAT radiation test geometry & resulting measurements

Table 6-I. ARBAT Radiation Test Results

	PT A			PT B			PT C		
Beam Elev Angle	-0.24°		±0.8°	-0.24°		±0.8°	-0.24°		±0.8°
Transmitter PCF (kHz)	5.2	10.0	10.0	5.2	10.0	10.0	5.2	10.0	10.0
Radiation Density (mW/cm^2)	0.4	1.0	0.85	0.85	1.6	0.4	0.3	1.75	N/A

Notes: Tests conducted with transmitter power output of 27 kW at 10 kHz.
Probe elevation optimized for highest density (approximately 7 ft above ground).

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6.2.3.2 Government Conducted Test and Recommendations – The following were extracted from: Nonionizing Radiation Protection Special Study No. 24-42-0729-79, Application of Radar to Ballistic Acceptance Testing Radar System, US Army Yuma Proving Ground, Yuma, AZ, 7-8 May 1979.

a) Instrumentation
   1. Narda Model 8300 Broadband Isotropic Radiation Monitor
   2. Raham Model 12 Broadband Electromagnetic Radiation Meter
   3. Victoreen Model 440 RF X-Ray Meter

b) Hazard Analysis and Microwave Measurements

A hazard analysis by the contractor had indicated that the maximum radiated power expected from the system was less than 10 mW/cm^2. This analysis was reviewed by this Agency and concurred in. Measurements made during this special study did not reveal any radiated power densities in excess of 10 mW/cm^2. In addition, there were no leakage levels detected in or around the transmitter or waveguide components. Table 6-II presents an analysis of the theoretical radiation parameters for the main beam of the ARBAT Radar System. The maximum anticipated power density level shown in Table 6-II is 7.4 mW/cm^2. The maximum level read during this study was 7 mW/cm^2. This level occurred at the antenna surface and decreased to 4 mW/cm^2 at 120 m. These levels were not subject to control under current DA standards. There would be hazardous power density levels associated with open waveguide or other nonstandard radiation configurations of the system. Table 6-III presents several levels of expected radiation vs. range for the open waveguide condition. Contractor personnel who presently operate the radar system reported that there were no occasions which called for transmitter operation in a nonstandard configuration.

c) X-Radiation Measurements

The transmitter used a traveling wave tube amplifier (TWTA) driven at 25 kV. X-radiation measurements made with the cabinet door closed showed a maximum 0.7 mR/hr level in the middle of the door, near the TWTA location. A maximum level of 1.2 mR/hr was measured with the doors open and interlocks bypassed. Contractor personnel reported that maintenance procedures included checks inside the cabinet with the TWTA on. A recommendation has been made in this report to mark the transmitter cabinet door (outside) and some conspicuous point inside with the standard propeller symbol for ionizing radiation areas.

Table 6-II. Microwave Radiation Parameters, ARBAT Radar System, Normal Configuration

Parameter	Description/Remarks
Transmitter Characteristics:	9.3 to 10.0 GHz; 28.5 kW Peak Power; 0.013 Duty Cycle (Max); Power Average 370 W.
Transmission Line Loss:	Waveguide to Array 1.0 dB; Waveguide in the Array 1.0 dB; Phase Shifter 1.5 dB. Total Losses: -3.5 dB; Power (Radiation): 370 X 0.45 (-3.5 dB) = 165 W.
Antenna Characteristics:	Area: 110,899 cm^2; Illumination Taper: 12 dB Area (Effective) = 88,719 (Ax 0.8) cm^2 Gain (Max) = 51.6 dB; Gain (X 0.6) = 49.4 dB.

Main Beam Radiation Characteristics:

Power Density (Maximum) = 4 P (Radiation)/A (Effective) = 7.4 mW/cm^2
Range of 7.4 mW/cm^2 = 124 m*
Range to 1.0 mW/cm^2 = 320 m

*Range (to Various Pd Levels) = $[P(\text{radiated}) \times G/4\pi \times Pd]^{1/2}$

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Table 6-III. Open Waveguide Radiation Hazard Analysis, ARBAT Radar System

Parameter	Description/Remarks
Waveguide Type:	RG-52U, 8.2-12.4 GHz Area: 3.23 cm^2; Gain (Est.): 6 dB
Maximum Power Density:	114 W/cm^2 (Power Transmitted/Area).

Power Density Change with Range:

- 100 mW/cm^2 @ 34 cm
- 10 mW/cm^2 @ 108 cm
- 1 mW/cm^2 @ 343 cm

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d) Conclusions

There were potential microwave radiation hazards associated with the use of the ARBAT Radar System. The procedures reported and observed during this study were adequate to prevent the radiation of such levels. Recommendations have been included to document the procedures that were in use. Implementation of those recommendations will assure a radiation protection program that meets the requirements of AR 40-5.

e) Recommendations (by Testing Agency)

1. Inventory the ARBAT Radar System as a potentially hazardous microwave source (paragraph 4-2, AR 40-5).
2. Prohibit operation of the radar transmitter in a nonstandard configuration (paragraph 5-31, AR 40-5).
3. Publish an adequate warning notice in all applicable technical or instructional manuals, etc., of the hazards associated with open waveguide or any nonstandard radiation mode of operation (paragraph 5-27, AR 40-5).
4. Post the standard ionizing radiation area warning sign both on the outside of the transmitter cabinet door and on the inside of the cabinet (paragraph 5-26, AR 40-5).
5. Inform all appropriate personnel of the potential hazards associated with the ARBAT Radar System, and the radiation protection program elements designed to control those potential hazards (paragraph 5-27, AR 40-5).

f) Followup Recommendations (by YPG)

The following were extracted from disposition executed by Munitions and Weapons Engineering Branch YPG.

1. In accordance with AR 40-5, Para 4-2(3) all sources of potentially hazardous electromagnetic radiation have been inventoried and identified to assure preventive measures are adequate to protect personnel.
2. Radar personnel have been warned that operation of the radar transmitter in a nonstandard configuration is strictly prohibited. Operations are closely monitored by supervisory personnel.
3. When instruction manuals are published instructions will include:
   a) Safe work procedures or handling techniques.
   b) Proper use of protective equipment.
   c) Proper use of radiation detection instruments and monitoring devices.
   d) Procedures to be followed when an accident occurs or in an emergency.
   e) Hazards involved with radar operation.
4. Standard ionizing radiation area warning signs have been posted outside transmitter cabinet door and on the inside of the cabinet.
5. All personnel associated with the ARBAT Radar System have been briefed on the potential hazards associated with the system and the radiation protection program elements designed to control potential hazards. Radiation control interlock switches utilizing a removable key are provided on the radar control panel in the operations van to protect personnel against inadvertant application of power to the radar transmitter when maintenance tasks are performed.

6.3 ENVIRONMENTAL CHARACTERISTICS

Formal environmental testing has never been envisioned for the ARBAT equipment. Nevertheless, the requirements of paragraph 3.4 (Environmental Requirements) of the ARBAT Scope of Work were adhered to as goals for performance. The best assessment of the success of the ARBAT design in meeting the goal is inferred from actual conditions encountered while in development testing at YPS. The following environmental data is presented to show conditions encountered during various tests. The data comes from the system log as well as data accumulated during the Demonstration Tests of 26 September through 4 October 1979. Finally, the environmental conditions shown are for periods where ARBAT performance was judged by operations personnel, or actual test results, to be normal in light of its point of development at the time of measurement.

6.3.1 Temperature/Humidity/Wind

Table 6-IV is a summary of Meteorological conditions during the Demonstrations of 26 September through 4 October 1979.

Table 6-V shows environmental extremes to date taken from the Site Log.

6.3.2 EMI Environment

No direct measurement of the EMI Environment at the ARBAT site or at adjacent operating sites have been made since ARBAT was installed at YPG. During this period however there has been no indication, from ARBAT performance or comments from other YPG radar users, that RF interference of any observable level exists.

Table 6-VI documents the YPG Range Instrumentation radars in use during the demonstration of 26 September through 4 October 1979.

Table 6-IV. Summary of Meteorological Data during ARBAT Demonstration

Date	Time	Temp °F	Humidity % Relative	Wind Avg. Mag	Wind Avg. Direct	Wind Peak
26 September 1979	9:35A	88	–	–	–	–
	10:00A	–	37	6 kt	–	9 kt
	12:00P	–	16	5 kt	–	13 kt
	2:15P	108	–	–	–	–
	3:00P	–	16	7 kt	–	14 kt
27 September 1979	10:00A	–	26	1 kt	SSE	None
	11:50A	96	–	–	–	–
	12:00P	–	19	2 kt	NNW	None
	12:35P	99	–	–	–	–
	1:45P	102	–	–	–	–
	3:00P	–	16	4 kt	WNW	None
28 September 1979	9:50A	87	–	–	–	–
	10:00A	–	48	2 kt	S	4 kt
	12:00P	–	30	2 kt	SE	8 kt
	12:15P	102	–	–	–	–
	2:20P	106	–	–	–	–
	3:00P	–	21	4 kt	SSE	11 kt
1 October 1979	10:00A	–	24	2 kt	SE	6 kt
	11:30A	93	–	–	–	–
	12:00P	–	15	1 kt	SSW	4 kt
	12:15P	94	–	–	–	–
	1:05P	96	–	–	–	–
	3:00P	–	15	4 kt	W	9 kt
2 October 1979	10:00A	–	21	0	–	2 kt
	11:30A	95	–	–	–	–
	12:00P	–	18	2 kt	W	6 kt
	2:36P	102	–	–	–	–
	3:00P	–	13	3 kt	NW	8 kt
4 October 1979	9:00A	–	22	1 kt	E	5 kt
	9:30A	87	–	–	–	–
	10:00A	–	–	–	–	–
	12:00P	–	15	3 kt	W	7 kt

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Table 6-V. Environmental Extremes to Date

Item	Date	Condition of Interest	Operation Being Performed
1	April 79	Operation in light rain	Tracking radar reflector during system checkout
2	21 June 79	Wind/20 Kt gusts	Tracking 81 mm Mortars
3	27 June 79	Ambient Temperature 117°F	System operated for Human Engineering measurements
4	28 June 79	Ambient Temperature 114°F	Tracking 81 mm Mortars
5	20 July 79	Ambient Humidity 86%	System up and down undergoing routine maintenance
6	26 July 79	Ambient Humidity 63%	Tracking 155 mm Howitzers

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Table 6-VI. Radar Range Instrumentation in Operation during ARBAT Demonstration Time Frame

Date	Radar	Site Used
26 September 1979	Hawk & TPQ-25	GP 7227 Eve
27 September 1979	Hawk & TPQ-25	GP 7227 Eve
28 September 1979	Hawk & TPQ-25	GP 7227 Eve
1 October 1979	GE 203A Muzzle Velocity Radar	GP18B (ARBAT Fire Site)
2 October 1979	Hawk & TPQ-25	GP 15
4 October 1979	MTS-25 High Power Hawk	Cibola Range Unknown

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Appendix A

SPECIFIC DEFINITIONS

Appendix A

SPECIFIC DEFINITIONS

AGC	Automatic Gain Control
ARBAT	Application of Radar to Ballistic Acceptance Testing of Ammunition (Acronym identifying U.S. Army ARRADCOM Radar program)
ARRADCOM	U.S. Army Armament Research and Development Command
az	Azimuth
BITE	Built-in Test Equipment
CFAR	Constant False Alarm Rate Detection Technique
CRT	Cathode Ray Tube
DARCOM	U.S. Army Development and Readiness Command
el	Elevation
FS	Firing Site
Full Trajectory	Projectile meeting the expected flight range
GF	Government Furnished
GFE	Government Furnished Equipment
GOF	Greatest of Filter
GP	General Purpose Processor
ICM	Improved Conventional Munitions
km	Kilometer
Launch	Exit from gun or rocket launcher
m/s, m/sec	Meter(s) per second
msec	Millisecond
MTI	Moving Target Indicator
NOVA	Data General copyright name: to be used interchangable with the Eclipse for the GP Processor
Partial Trajectory	Projectile falling short of the normally expected flight range
prf	Pulse Repetition Frequency
PRT	Pulse Repetition Time
QE	Quadrant Elevation (Launch angle with respect to horizontal)
RAP	Rocket Assisted Projectile
rcs	Radar Cross Section
Round	Ammunition for one shot fired by a gun
SPP	Special Purpose Processor
Time of Flight	Elapsed time in seconds from the instant a projectile leave the gun until the instant it strikes or bursts
Trajectory	Curve described in space by the center of gravity of a projectile

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This report covers the results of the activity on the ARBAT Program (Application of Radar to Ballistic Acceptance Testing of Ammunition) through 5 October 1979. Included in this report are: A Technical Description of the Radar System, description of the System Operation and Operational Procedures, and Description and Analysis of the Performance Demonstration Test Results. Performance Demonstration Test results indicate that: the System Concepts have been proven; The ARBAT radar system is capable of tracking artillery projectiles while providing real-time analysis, display of the trajectory characteristics, and permanent magnetic tape storage of the trajectory data for further off-line analysis.

20. Abstract (Continued)

The ARBAT Radar System is a range instrumentation radar optimized for the R&D and ballistic testing of ammunition projectiles. This radar provides test parameters of the projectile trajectory which are not currently measurable. The data output of the radar is available both on real-time displays, and as a permanent record for use in further off-line analysis.